EVALUATION OF HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM AND WASTE HEAT RECOVERY

At Inuvik, N.W.T.

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EVALUATION OF HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM AND WASTE HEAT RECOVERY AT INUVIK, NORTHWEST TERRITORIES

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ABSTRACT

The objectives of the study were

- to determine what changes, if any, are needed to make Inuvik's high temperature water (HTW) heat distribution system safe and reliable, and

- to determine what changes, if any, would enhance the HTW system's economics: in particular, if recovery and distribution of heat lost from diesel generators of electricity might be cost-effective.

As described in the first volume of the report, the HTW system is strongly built and shows few signs of aging. Some maintenance needs were observed, and are described. Some expansion joints need to be replaced each year. Most consumers' connections to the system are properly designed and installed; a small number should be altered to improve safety.

The second volume of the report discusses system capacity and efficiency, and the potential for use of waste heat. The distribution system's capacity exceeds current peak demands by about 10 percent, and there is ample boiler capacity. The system's overall efficiency on an annual basis is about 73 percent, and cost effective improvements might increase this figure by one to two percent. At current price levels for HTW heat and heating fuels, the HTW system is believed to enjoy a slight cost advantage over independent building heating systems.

Recovery and distribution of waste heat does not appear to be particularly attractive. Heat recovery equipment and necessary modifications would cost about $4.8 million, and the saving is estimated to be $623,000 per year. The payback period would be 7.5 years, simple, and 12.5 years at 8 percent.

EXECUTIVE SUMMARY

Inuvik's high temperature water (HTW) heat distribution system was built in the late 1950's. It now serves 243 buildings, and a small number of other consumers. Heat lost from HTW pipes keeps water and sewage mains from freezing in about half of Inuvik's utilidor system. All heat is generated by large boilers, installed in NCPC's powerhouses.

The purposes of this study are to determine what changes, if any, are needed to make the HTW system safe and reliable, and what changes, if any, might enhance the HTW system's economics. In particular, the possibility of recovering and distributing heat now wasted from diesel electric generators was analysed.

The HTW system shows few signs of aging, but some maintenance work is required. Distribution pipes show no sign of corrosion. Expansion joints are the only components which have been prone to failure: some need to be replaced each year. The type of joint seems appropriately chosen, but many existing joints appear to have been sized for a shorter traverse range than is desirable. Some may not have been installed at optimal compression for the installation temperature.

Most consumers' connections are appropriately designed, but a few should be rebuilt in the interest of safety.

The HTW system passes below a number of buildings, in most cases without risk to the security of the system. However, a serious fire in Samuel Hearne Secondary School could cut services to a large number of consumers to the north, and could endanger a large section of the water distribution system. The risk could be eliminated by building a redundant loop around the school, available for use in an emergency.

NCPC's heat generation plant has sufficient capacity to satisfy current loads. There is ample reserve boiler capacity for peak loads, and about 90 percent standby against failure of the largest unit. Reserve capacity in the distribution system amounts to 10 to 20 percent of current peak load.

About 73 percent of the energy input into the HTW system as fuel actually reaches consumers in the community or in the powerhouse area. The other 27 percent is lost, 13.5 percent in boiler flue gases, 5.3 percent elsewhere in the powerhouse, and 8.2 percent from the utilidor system. Utilidor heat losses could be reduced to 7.2 percent by cost-effective re-insulation measures, and to 6.6 percent by cooling HTW system temperatures in warmer months. Howerver, the latter measure could substantially increase expansion joint maintenance costs.

Energy conservation retrofit measures, even if widely applied in HTW consumer buildings, would not be likely to reduce HTW heat demand levels by more than 10 percent.

The HTW system has some inherent economic advantages over independant building heating systems. These include highly efficient industrial boilers, and the use of heavy fuel, which is less costly than the lighter grade home heating fuels.

The system's principal disadvantages are the heat lost by the HTW distribution system and, if it is considered, the capital cost of the distribution mains. Cost analyses indicate that, if the latter factor is neglected, it is slightly less costly to purchase heat from the HTW system than it is to install boilers and generate the same heat independently.

Consumption of HTW heat is not metered. It is believed that the somewhat arbitrary nature of the HTW heat billing system has contributed to loss of

customers. Metering is costly, but would increase customer satisfaction, and would encourage heat conservation among consumers.

There does not appear to be any opportunity to capture heat wasted from the HTW boilers.

On the other hand, heat could be recovered from diesel engine jackets and stacks. The amount recoverable is much larger than could be used in the powerhouses, to heat fuel, and to heat domestic water at the water plant.

Heat is recoverable at a temperature between 225°F and 240°F, if stack heat is added after recovery of jacket heat. In order to use the greater part of recoverable quantities of waste heat, it would be necessary to distribute heat to a number of buildings at temperatures in this range, which is significantly below the HTW system's supply temperature of 350°F. This would involve converting some utilidor and some building heat exchangers for operation at the lower temperature range. Other elements of building heating systems would not be changed.

The cost of heat recovery equipment, utilidor additions and modifications, changes to building heat exchangers and other alterations is estimated to be $4.8 million. The annual saving is estimated to be $623,000 per year. The simple payback period would be 7.5 years, and the payback at a discount rate of 8 percent per year would be 12.5 years.

The economics of recovery and distribution of the major part of the heat now wasted are, therefore, only marginal. It must be noted, too, that economic forecasts such as these are very sensitive to changes in the real and relative levels of fuel prices, and to change in the discount rate.

However, analysis also shows that it may be cost effective to capture about half of the engine cooling heat now wasted, for use within NCPC's yard area.

Other opportunities for enhancing system economics are minor, being confined to replacing pipe insulation which has been lost within vaults and in a small number of utilidor runs.

ÉVALUATION DU SYSTÈME DE DISTRIBUTION DE LA CHALEUR DE L'EAU À TRÈS HAUTE TEMPÉRATURE ET POSSIBILITÉ DE RÉCUPÉRER LA CHALEUR RÉSIDUELLE À INUVIK (T.N.-O.)

Résumé

C'est vers la fin des années cinquante qu'on a construit à Inuvik un système de distribution de la chaleur provenant de l'eau à très haute température. À l'heure actuelle, il dessert 243 bâtisses et un petit nombre d'autres consommateurs. La chaleur provenant des canalisations d'eau à très haute température empêche les conduites d'eau principales et les conduites d'égoût principales de geler. La moitié du réseau de distribution sous coffre de la collectivité d'Inuvik contient les canalisations de distribution d'eau à très haute température. La chaleur est produite par de grandes chaudières, installées dans les centrales électriques de la Northern Canada Power Commission (N.C.P.C.).

Cette étude a pour but de déterminer les changements possibles à apporter afin de rendre ce système sécuritaire et fiable et d'en augmenter la rentabilité. L'étude a porté plus particulièrement sur la possibilité de récupérer et de distribuer la chaleur résiduelle provenant des groupes électrogènes diesels.

Comme il est mentionné dans le premier volume de ce rapport, ce système présente peu de signes d'usure, il est nécessaire, toutefois, de procéder à certains travaux d'entretien. Les canalisations de distribution n'ont pas été attaquées par la corrosion. Ce sont les joints de dilatation qui posent le plus de problèmes: quelques-uns doivent être remplacés chaque année. À première vue, le type de joint choisi semble convenir, il demeure que bon nombre de joints semblent avoir été dimensionnés pour une plus petite zone d'expansion que souhaité. Quelques-uns n'ont peut-être pas été installés sous compression optimale pour la température d'installation. La plupart des raccords sont bien conçus, mais quelques-uns devraient être reconstruits pour la sécurité des consommateurs.

Le système de distribution d'eau à très haute température passe sous un certain nombre de bâtisses et dans la plupart des cas il est à l'abri des sinistres. Mais s'il se produisait un incendie d'importance à l'école secondaire Samuel-Hearne, par exemple, un grand nombre de consommateurs vivant au nord de la ville pourraient être privés de services; de même, une section importante du système d'aqueduc pourrait être touchée. Tout cela pourrait être évité en construisant une canalisation en parallèle autour de l'école et qui serait disponible en cas d'urgence.

Selon le deuxième volume de ce rapport, la centrale de chauffage de la N.C.P.C. produit suffisamment d'énergie pour répondre à la demande courante. Les chaudières peuvent facilement répondre à la demande pendant les périodes de pointe de même qu'à environ 90 % de la demande au cas où la plus grosse chaudière tomberait en panne. La capacité de réserve du système de distribution totalise de 10 à 20 % de la demande pendant les périodes de pointe.

Environ 73 % de la chaleur produite et qui circule dans le système atteint effectivement les consommateurs situés dans la collectivité ou aux environs de la centrale. La tranche de 27 % qui reste est perdue. Ainsi, 13,5 % s'échappe sous forme de gaz de combustion produits par les chaudières, 5,3 % est perdu ailleurs dans la centrale électrique et 8,2 % est perdu dans le réseau de distribution sous coffre. Les pertes de chaleur du réseau de distribution aérien sous coffre pourraient être réduites de 7,2 % en améliorant l'isolation des conduites et de 6,6 % en abaissant la température des conduites d'eau à très haute température les mois où il fait plus chaud. Cette dernière mesure pourrait, toutefois, augmenter de beaucoup les frais d'entretien des joints de dilatation.

Même si les mesures d'économies d'énergie étaient appliquées dans toutes les bâtisses desservies par le système de distribution d'eau à très haute température, la demande de chaleur ne pourrait être réduite, selon toute probabilité, de plus de 10%.

Le système de distribution d'eau à très haute température possède certains avantages au plan économique sur les systèmes de chauffage individuels. Mentionnons par exemple: l'utilisation de chaudières industrielles à très haut rendement et l'utilisation de combustible lourd, moins coûteux que le mazout léger utilisé pour le chauffage résidentiel.

Les pertes de chaleur provenant du système de distribution d'eau à très haute température et les frais d'immobilisations des conduites de distribution principales constituent les principaux désavantages du système. Une analyse des coûts montre (en ne tenant pas compte, toutefois, du dernier facteur) qu'il est à peine plus rentable d'acheter de la chaleur provenant du système de distribution d'eau à très haute température que d'installer des chaudières et de produire de la chaleur de façon individuelle.

La consommation de chaleur provenant du système de distribution d'eau à très haute température n'est pas mesurée à l'aide de compteurs. On croit que la façon quelque peu arbitraire de facturer l'énergie thermique provenant du système a contribué à la baisse de la clientèle. Bien que l'installation de compteurs soit coûteuse, la clientèle serait plus satisfaite et cela permettrait de sensibiliser les utilisateurs a économiser de l'énergie.

Quoique la possibilité de récupérer la chaleur résiduelle provenant des chaudières du système de distribution d'eau à très haute température ne semble pas devoir se réaliser, on pourrait, par contre, récupérer la chaleur résiduelle de l'eau de refroidissement et de l'échappement de moteurs diesels. La quantité de chaleur récupérable dépasse grandement

l'utilisation qui pourrait en être faite dans les centrales électriques soit pour chauffer le combustible, ou à la centrale hydraulique soit pour chauffer l'eau domestique.

La chaleur est récupérable à une température variant entre 225°F et 240°F si la chaleur résiduelle de l'échappement est ajoutée après récupération de la chaleur provenant de l'eau de refroidissement. Afin de maximiser l'utilisation de la chaleur résiduelle, il serait nécessaire de distribuer la chaleur à un nombre de bâtisses à des températures de cet ordre, ce qui est bien au-dessous de la température du système qui est de 350°F. Cela se traduirait par la conversion d'échangeurs de chaleur dans certaines parties du réseau de distribution sous coffre et dans certaines bâtisses pour pouvoir fonctionner à de plus basses températures. Toutefois, il ne serait pas nécessaire d'apporter des modifications aux autres composantes du système de chauffage des bâtisses.

On estime à 4,8 millions de dollars, les frais reliés à l'équipement de récupération de la chaleur, aux modifications et ajouts apportés au réseau de distribution sous coffre et aux échangeurs de chaleur des bâtisses. Les économies annuelles sont estimées à 623 000 $. La période de récupération simple serait de 7,5 années et la période de recouvrement serait de 12,5 années à un taux d'actualisation de 8 % par année.

La récupération et la distribution de la majeure partie de la chaleur résiduelle s'avèrent très peu rentable. Notons aussi que ces prévisions économiques sont très sensibles aux fluctuations réelles et relatives du prix du combustible ainsi que du taux d'actualisation.

Cependant, l'analyse économique démontre aussi qu'il peut être rentable de récupérer environ la moitié de la chaleur résiduelle provenant de l'eau de refroidissement des moteurs au profit de la N.C.P.C. .

Les autres possibilités qui pourraient concourir à augmenter la rentabilité du système se résument à remplacer l'isolation des conduites à l'intérieur des voûtes et dans certaines parties du réseau de distribution sous coffre.

Cette étude a été préparée pour le gouvernement des Territoires du Nord-Ouest par l'Associated Engineering Services Ltd. avec une subvention d'Énergie, Mines et Ressources Canada et du gouvernement des Territoires du Nord-Ouest dans le cadre du Programme de démonstration dans les collectivités éloignées.

VOLUME I - SAFETY AND RELIABILITY

INTRODUCTION AND SUMMARY

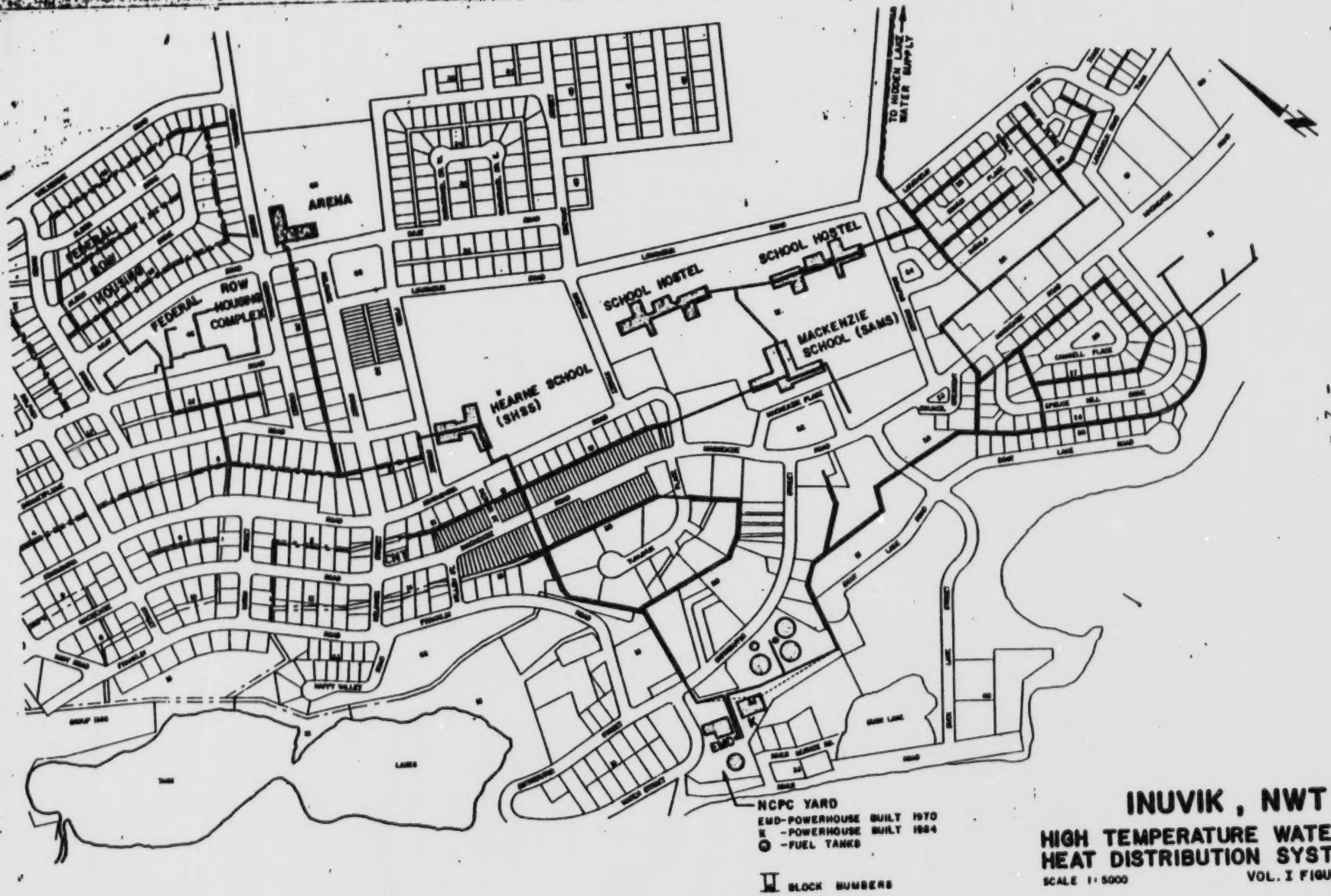
Inuvik was founded in the mid-1950's, born of the Federal Government's need for a regional service and administrative centre near the mouth of the Mackenzie River.

It was decided that the new community's planners and engineers should use, and test, the most advanced cold regions concepts and technology then available. Inuvik's ice-rich, thaw-sensitive permafrost soils dictated that water and sewer piping be above ground, which led to the planning of Inuvik's now widely known utilidor system. At the same time, it was decided to provide heat to most or all buildings from a central plant, using a high temperature water (HTW) heat distribution system.

It is likely that the decision to build central heating was influenced by both the utilidor system's need for heat to prevent freezing, and the expected efficiency of a central plant. More importantly, however, it was intended that electrical generators would be driven by steam turbines, and that the HTW system's heat would be taken from the turbines' exhaust, an arrangement which would achieve a high degree of fuel efficiency throughout the winter. As it happens, NCPC* has moved away from co-generation of electricity and heat, owing primarily to the inefficiency of this system in summer. All electricity is now generated by diesel units. There has to date been no recovery of heat from the engines, but the new plant recently commissioned has provision for capture and use of some heat from waterjackets. Heat for the HTW system is now provided by large hot water boilers, installed solely for that purpose.

High temperature water heat distribution mains were installed, along with water and sewer mains, in all of Inuvik's utilidors built between 1958 and 1971, including the run from the school residence blocks to Hidden Lake. As can be seen in Figure 1, the HTW system was also extended north to the

*Northern Canada Power Commission



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE 1:5000 VOL. I FIGURE I

CNT building, across Inuit Road to the arena, and to the apartment building at the south end of Block 37. At the same time, it was not built into Co-op Hill,* the west end residential areas, or any main runs of utilidors built after 1971.

The HTW system is found in some 5.3 miles (8.6 km) of utilidor, just over half of Inuvik's total of 10 miles (16 km).** It now provides heat to 243 buildings, and to other users, of which fuel storage tanks and the domestic water system are examples, through 13 additional connections. Supply and return pipes are welded steel, in sizes up to 8-inch, and the flow rate at the powerhouse is 1200 to 1300 Igm. The peak heating load is in the neighbourhood of 69 million BTU/hr. Consumption of heavy fuel ranges from 2600 Igd in summer to 9200 Igd during cold winter weather, and totals 2.2 million gallons per year. Output and return temperatures are 350°F and 250 to 280°F respectively, and system pressures are 200 to 250 psi.

A primary reason for the decision not to include HTW piping in utilidors built during the last decade or so is the very high capital cost of welded steel piping, larger utilidor box, restraints and expansion features, and building connections. In recent years, however, a more compelling reason has been the very high cost of HTW heat, relative to alternatives. Some non-government consumers have installed their own building heating facilities, and gone off the HTW system. In discussions, two have reported capital cost payback periods of under two years.

*Blocks 32, 34, 35 and 40.

**The HTW system was built of components made to imperial measurement standards, and most data and records are in imperial units. The Study Management Committee elected to use imperial units in this study as well, for consistency.

For obvious reasons, the economics of the HTW system have become a source of concern. Questions have also been asked about the system's condition, reliability, and safety, in view of its age. In June, 1984, the Department of Public Works, Government of the Northwest Territories retained Associated Engineering to investigate and report on these two issues. The work was done under the guidance of a Study Management Committee, whose membership includes representatives of the Department of Public Works and Highways and Department of Local Government, Government of the Northwest Territories; Department of Energy Mines and Resources, Canada; NCPC, Town of Inuvik and the Consultants.* This, the "Phase I" report, deals with the condition of the system, and matters affecting safety and reliability. A "Phase II" report, bound separately, deals with the system's operational characteristics and options for improving its economics; in particular, the potential for recovery and distribution of heat rejected and lost from diesel generators.

In general, the HTW system is strongly built, well maintained and quite reliable. Most components show only minor signs of aging.

NCPC's heat generation facilities appear to be sound, reliable, in good condition and well supervised. Slightly better security could be achieved by dividing boiler capacity equally between the two powerhouses, but the minor benefit would not warrant the cost. More importantly, the current practice of heating fuel in storage tanks directly by high temperature water is a serious threat to the security of both the fuel and the HTW system. It is strongly recommended that tanks be heated by an independant glycol system.

The utilidor system and the HTW distribution piping are, in general, very sound. Pipes show no detectable signs of corrosion. Pipe insulation is missing at most vaults, but is in good condition within most runs of

*Committee Members and others who participated in Committee proceedings are listed in Appendix II.

utilidor. Piles show signs of butt rot at a few locations: these and other maintenance needs discovered in the course of sampling inspections are listed in the report.

Leaks in expansion joints are a maintenance nuisance, and the possibility that a joint bellows might fail abruptly, and cause injury or lead to freezing of a section of the system, is a source of concern. It appears that the expansion joints now used in the system are the best of available choices. On the whole, the number of expansion joint failures has been small, and would probably be reduced if the joints were sized (and installed) for the full range of traverse to be expected, including summer cooling.

The majority of consumer connections are properly designed, but many receive no preventative maintenance. No connections other than NCPC's fuel heaters pose any great threat to the reliability of the HTW system as a whole. There are a few connections in which high temperature water is piped through building heating facilities in public or residential buildings: these are dangerous and should be modified. It is recommended that the division of responsibility between NCPC and building owners be reconsidered. In our view, there would be significant advantage in having a single agency responsible for design standards and for the maintenance of all facilities through which the high temperature water flows.

Another matter to be given consideration is the safety of personnel working on both the HTW distribution system, and consumer connections. High temperature water is quite dangerous. There are several ways in which risk of injury, or death, could be reduced, most of them at quite modest cost.

These and other recommendations are summarized in Part IV of the report. Parts I, II and III discuss, respectively, heat generation, the distribution system and consumer connections.

PART I

HEAT SUPPLY FACILITIES

The sections in Part I of the report deal with heat generation, and related main-plant installations, with the object of identifying any limitations in capacity, and any weaknesses which would affect reliability.

Part II deals with the distribution system itself, and Part III with the consumers it serves.

HEAT GENERATION

Introduction

Currently, all heat distributed by the HTW system is generated by oil-fired boilers, located in NCPC's two powerhouses.* The layout of NCPC's plant and fuel storage yard is shown in Figure 2.

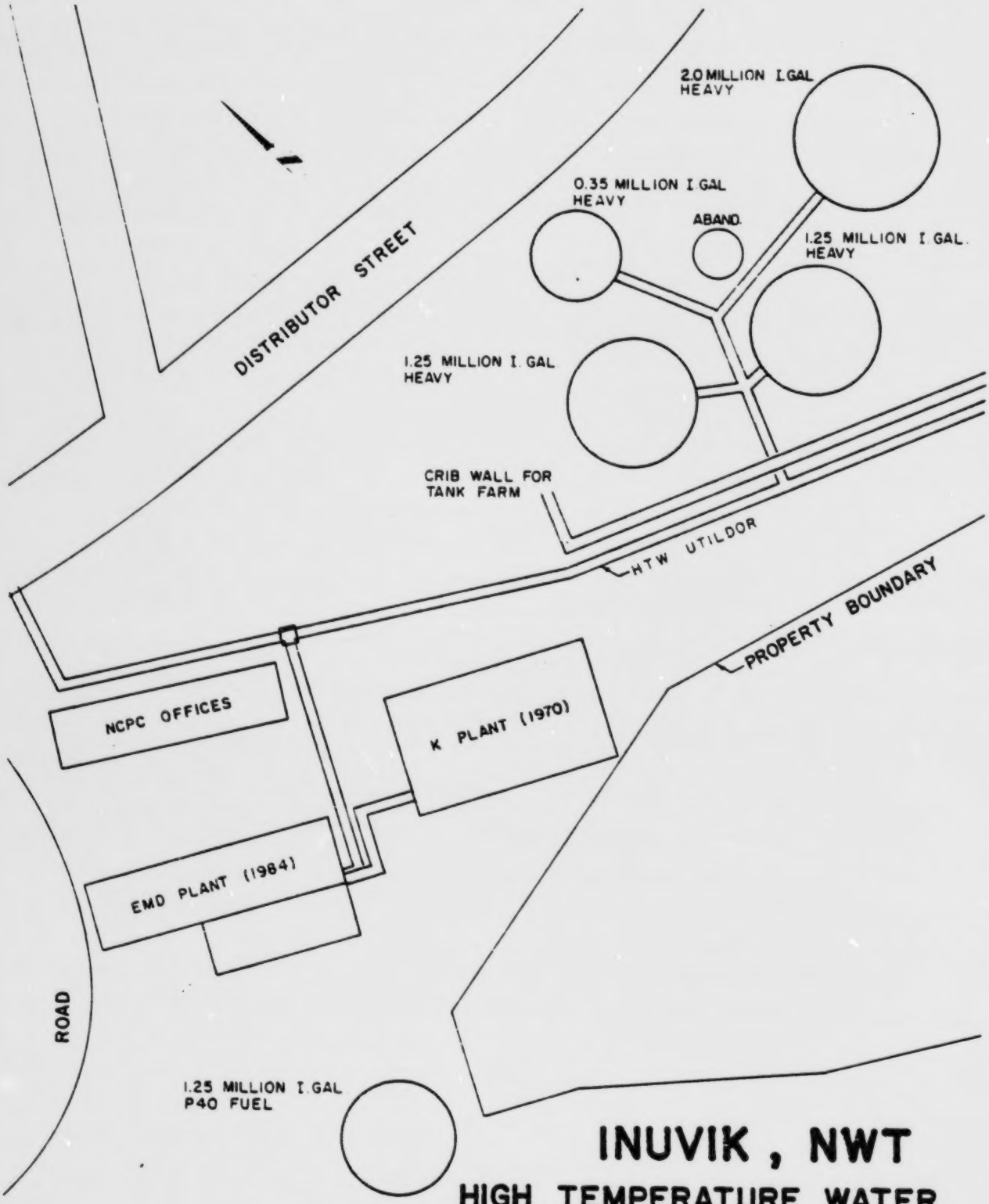
The objectives are to assess the capacity and condition of existing boilers.

Scope of Investigation

The boilers were examined, briefly, in the course of field work. NCPC operations personnel provided information on the age and capacity of each unit, fuels used, arrangements for the supply and storage of fuel and the

*The "old" powerhouse was built about 1958, and was destroyed by fire in 1983. The "K" plant was built in the early 1970's, and is now sometimes called the "old" plant. The "EMD" plant was built in 1984, to replace the one lost by fire.

HEATING PLANTS AND OIL STORAGE TANKS



INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE 1:100

VOL. I FIGURE 2

heating of heavy fuel, operational practices, past and foreseeable system failures, and contingency plans. They also described the philosophy and priorities which govern operation of the heat and electricity generation plant as a whole, under normal and abnormal conditions.

Installed Boilers

Heat is provided by the three boilers described in Table 1.

TABLE 1

INSTALLED BOILERS

Unit	Make	Capacity Million BTU/Hr	Built	Location
1	Cleaver Brooks	30	1976	K
2	Cleaver Brooks	63	1983	EMD
3	Volcano	90	1971	K

All three boilers are understood to be in very good condition. The controls for the large Volcano boiler were destroyed in the 1983 fire but have since been replaced.

The three boilers have forced draft modulating burners and all other usual devices which enhance efficiency. None have equipment for flue gas heat recovery.

Operation, Monitoring and Supervision

The HTW system's heat requirement approaches 70 Million BTU/Hr on very cold days, and exceeds that level only infrequently, by small amounts. Even during sustained cold weather, demand can normally be satisfied by the Volcano boiler alone, or by the two Cleaver Brooks units together. Consequently, the system has 100 percent standby coverage against failure of any of its units, including the largest.

In day-to-day operation, NCPC uses whichever boiler, or combination, appears appropriate according to the total heating load. Apart from the choice of which boiler to fire, and valve changes to bring it on line, operation is automatic.

The three boilers are fitted with all normal monitoring devices and alarms, including fire and flame outage, high and low pressure, high and low temperature, low flow, and fuel pressure. The powerhouse is manned by one operator and one shift engineer at all times. Total staff allocated to plant supervision comprises six operators, six Class 2 steam engineers, and one Class 1 steam engineer in overall charge.

Fuel Supply

NCPC fires all boilers with a heavy fuel, "No. 5" or "Bunker C".

The fuel is produced in Norman Wells, and moved to Inuvik by barge. Current consumption by the HTW system boilers is about 2.25 million Ig (Imperial gallons) annually, plus or minus 10 to 15 percent according to the severity of the winter.

NCPC's tank farm, located 50 m east of the powerhouses, stores 4.85 mig* of heavy fuel in four tanks. The largest tank holds 2.0 mig. In

*Million Imperial Gallons

addition, 1.25 mig of P40 (arctic diesel) fuel is stored in a single tank located 30 m south of the EMD plant.

The diesel electric generators in the EMD plant burn only the light P40 fuel. The engines in the K plant are more versatile, and can be run on either light or heavy fuel. Typically, some heavy fuel is used for electrical generation in the course of a year, the amount depending on both the sharing of load between the two plants, and the choice of fuel used in the K plant. Choices no doubt are based in part on equivalent cost per net power produced. The amount of heavy fuel used for power generation was 1.27 mig in 1982, 0.87 mig in 1983, and 1.64 mig in 1984. P40 use in the same three years, all for power generation, was 1.28, 1.29 and 0.49 mig respectively.

Considering only 1984, in which heavy fuel use was relatively high, heavy fuel storage now exceeds annual use by about 25 percent.

Heavy fuel will not flow at temperatures much below 80°F, so immersion heaters are installed in the storage tanks, near the outlet. One of the main HTW distribution branches runs nearby, and high temperature water is run directly through the immersion heater coils. Supply and return lines can be shut off by valves at the utilidor main, and the pipes to and from each tank are similarly valved. The flow through each tank coil is set manually.

Boiler Makeup Water

The boilers are not isolated from the HTW system by a separate heater circuit and heat exchanger interface, as is sometimes done, and there would be no advantage in such an arrangement. Rather, the boiler heating tubes are part of the HTW circulation loop, which provides maximum heat transfer efficiency. Returned high temperature water flows directly

through the boilers, and back out to the supply side of the distribution system.

Therefore, there is no separate boiler makeup system. The makeup system supplying water to the HTW distribution system fills that need.

Experienced Failure Events

Actual interruptions in heat supply have, to date, been few, and nearly all of very short duration. Interruptions, near interruptions and alarm conditions which have occurred resulted from

- contamination of fuel by leaking heating coils,
- major fire,
- controls failure, and
- operator error.

As mentioned earlier, heavy fuel is heated in its storage tanks, by running high temperature water through immersion heaters. Before the immersion heaters were installed, about 1974, NCPC's practice was to heat the entire tank, by running high temperature water through coils fixed to the tank floor. As is reported later, NCPC has been highly successful in controlling corrosion in the HTW system, and quite reasonably did not expect corrosion of the inside surfaces of tank heating coils. Outside surfaces were thought to be protected as well, being immersed in oil at all times. In consequence it was believed that the risk of a perforated heating coil was very small. As it happened, water from a variety of sources, such as water left in fuel barges and fuel supply pipes from cleaning, and water from condensation within the tanks, accumulated in a layer at the base of the tank, around the coils. The pipes corroded, no doubt rapidly in view of their high temperatures. When the HTW system was shut down for repair in the summer of 1974, fuel leaked back into the

de-pressurized circulation system, and led to the discovery of an entire storage tank of fuel heavily contaminated with alkaline water from the HTW system.

Stored supplies (and occasional minor spills) of fuel oil, lubricants and cleaning solvents combine with the frequent welding work of minor changes and repairs to make powerhouses vulnerable to fire. A number of fires have occurred in the NCPC plant area, the most serious being the 1983 fire which destroyed the original powerhouse.

Currently, the boilers are distributed among two powerhouses, so one serious fire would not be expected to put the HTW system's only heat source entirely out of action. Loss of the "K" powerhouse would limit heat production to 63 million BTU/Hr, a little over 90 percent of peak demand. Temperatures in all consumer buildings could be kept above to 50°F under extreme cold weather conditions, if heat could be distributed more or less evenly throughout the system. To balance the sharing of heat would, however, require manual throttling of some consumers' valves, so could be difficult to achieve under changing weather conditions.

Occasionally a boiler may fail to start, or will shut down due to some malfunction or failure in a monitoring or control device. Minor problems of this sort are dealt with in a routine way by operations staff, and they are not of significance to system reliability. If the trouble cannot be located and fixed forthwith, the next boiler is brought on stream.

The problem of operator error is more complex. The plant itself is complex, and it would be difficult to imagine all of the things that might be done incorrectly, or inadvertently, which might lead to a problem condition, especially one which might not be detected until real inconvenience or damage followed.

The most dramatic example reported by NCPC personnel occurred during cold weather in December, 1982, when an operator opened the wrong valve, and inadvertently began to drain the HTW system into the sewer. It could be seen in the plant that system pressure was falling, and a search was undertaken throughout the town for a broken pipe, which would have been marked by billows of steam. After a time, the real origin of the problem was found, and the HTW system was refilled and restarted, gently, to minimize thermal shock.

NCPC in Inuvik has been, and continues to be, very fortunate in having some highly capable and dedicated supervisory and technical staff. These are, however, few in number, so considerable responsibility is also carried by staff who have not had either extensive technical education, or the advantages of long apprenticeship in the Power Commission's service. NCPC suffers, as do all northern employers who need particularly skilled personnel, from the shortage of such persons locally, and the difficulty of hiring them from the south and then keeping them in the north. The shortage of skilled operators increases the chances of operator error.

Potential Failure Events

Fire remains the most serious threat to the central plant facilities. The new EMD plant is entirely of non-combustible construction, which is a great improvement over oil-absorbing wood floors concealed in crawl spaces. The better building makes housekeeping easier, which should reduce both the incidence and severity of fires, and make fire suppression easier as well.

Both powerhouses are now monitored by ultraviolet smoke detectors and heat detectors. The EMD plant engines have full flooding dry chemical systems, and switchgear rooms are protected with automatic halon systems. Fire fighting equipment in the older K plant includes a 150 pound dry chemical extinguisher on wheels, and 20 pound manual dry chemical extinguishers.

The potential for operator error probably is the next concern, a distant second to fires. Past mistakes have, on the whole, not had serious consequences. The new controls, monitoring and alarm systems being installed throughout the plant, as part of the 1983-84 rebuilding, will further reduce the liklihood of error, or of an error proceeding undetected to some unpleasant consequence.

NCPC operations personnel consider that it would be impossible to foresee every possible control mistake that might be made. Their view, which is surely correct, is that the only solution to such problems is to hire, train and keep skilled staff, who will make few mistakes, and respond quickly and correctly when problems do occur.

Finally, the arrangement whereby fuel is heated directly by high temperature water is thought to present unnecessary risks to the security of both the fuel supply and the HTW system. As the past has shown, a leaking heating coil may go undetected for a long time, with expensive results.

Conclusions and Recommendations

The distribution of the boilers between the K and EMD plants provides a reasonably good level of security against fire, which is the principal threat to central plant facilities. Had the large Volcano boiler been housed in one plant and the two Cleaver Brooks units in the other, then either plant alone would have been able to satisfy normal maximum demand, and security would have been virtually complete.

In comparison to fire, other risks are thought to be much less serious.

It is recommended that consideration be given to heating fuel in storage by a secondary, glycol system, operated at atmospheric pressure, rather than directly by high temperature water.

CIRCULATION PUMPS, EXPANSION TANKS AND OVERFLOW TANKS

Introduction

The principal central plant components that the HTW system depends on, besides the boilers, are

- pumps, which maintain circulation flow in the distribution system,
- an expansion tank, which compensates for volume changes in the circulating water and piping, due to changes in temperature, and
- an overflow tank, which acts as a reservoir for the expansion tank.

Figure 3 is a schematic flow diagram showing the relationship of these components.

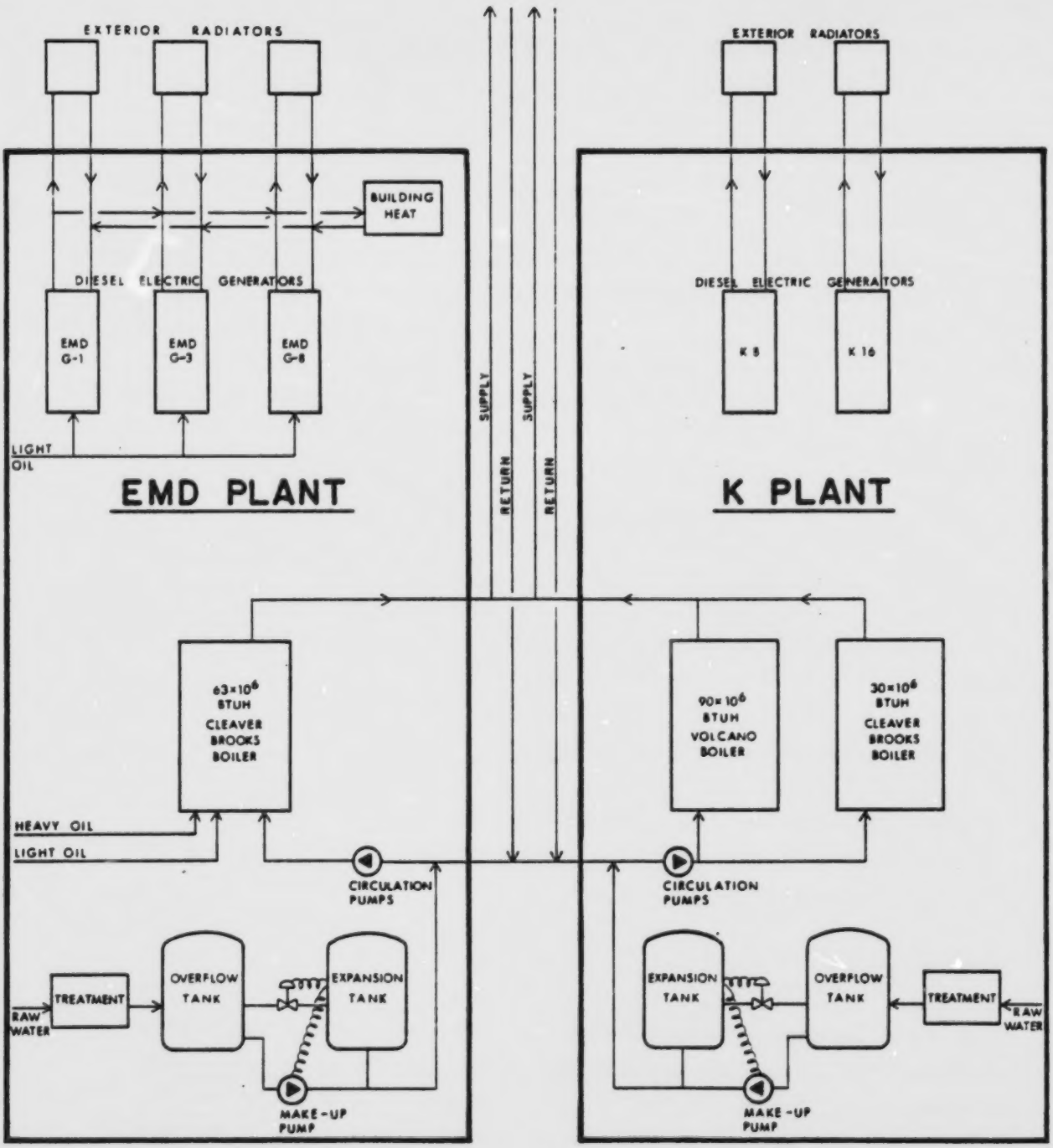
Scope of Investigation

The pumps and tanks were seen during field inspections. NCPC operating personnel provided pump data, pump operating curves and information on operations procedures.

Installed Pumps

Three Byron Jackson circulation pumps are installed in the K powerhouse, and two similar pumps have recently been put in the EMD plant. Each pump is rated at 900 USgm at 198 feet of head, and driven by a 100 hp electric motor. Only one is used at any time to maintain circulation in the HTW distribution system.

SIMPLIFIED POWER HOUSE SCHEMATIC



INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE N.T.S. VOL. I FIGURE 3

The pumps are serviced regularly by NCPC maintenance personnel, and appear to be in good condition.

Expansion and Overflow Tanks

Expansion tank and overflow tank systems are installed in both the K and EMD plants; only one of those systems is needed at any time. Expansion tanks operate at HTW system return pressure of about 200 psi (1.38 MPa). They are capped with nitrogen, oxygen being excluded from the HTW system as a corrosion control measure.

The overflow tanks also operate above atmospheric pressure, and act as reservoirs for the expansion tanks.

Operation, Monitoring and Supervision

Expansion tanks automatically dump to overflow tanks on reaching a high level set point. Overflow tanks automatically discharge to sewer at high level. Makeup water is automatically pumped to the expansion tank from the overflow tank, as needed to maintain minimum level in the expansion tank. Similarly, overflow tanks will draw automatically from the plant potable water system, if necessary. Operators normally add water to overflow tanks as needed, and batch feed conditioning chemicals at the same time.

Circulation pump failure would be recognized by the boiler low flow monitor, and the alarm would be given from the boiler panel.

Experienced Failure Events

The accidental discharge of high temperature water described earlier involved inadvertant opening of an expansion tank discharge (to sewer) valve.

No other failure events of significance are known.

Conclusions and Recommendations

Pumps and the expansion tank — overflow tank systems appear to be in good condition, and are well backed up.

No changes appear to be warranted.

PART II
DISTRIBUTION SYSTEM

Part I of the report dealt with the facilities which generate the heat which the HTW system distributes. Part II deals with the distribution system itself. The topics addressed include

- the system and its components (overview description),
- structural condition,
- pipe restraints, and expansion-contraction features,
- corrosion in pipe mains,
- the significance of having the HTW system pass through buildings, and
- system reliability, and potential improvements.

HTW DISTRIBUTION SYSTEM

Introduction

The HTW system is an integral part of Inuvik's 1958 to 1971 ("original") utilidor system. This introductory section presents brief descriptions of the original utilidor network, of later additions of different designs which also contain HTW mains, and of system vaults and the HTW piping itself.

Scope of Investigation

System layout information was obtained from NCPC's head office files, in the course of developing system base plans. Other information was gathered in the field. The field investigation included visits within all vaults, removal of utilidor siding at 54 locations to examine expansion

joints, pipe guides, anchors and insulation, and exterior examination of all utilidor runs and building connections which carry HTW piping.

System Layout

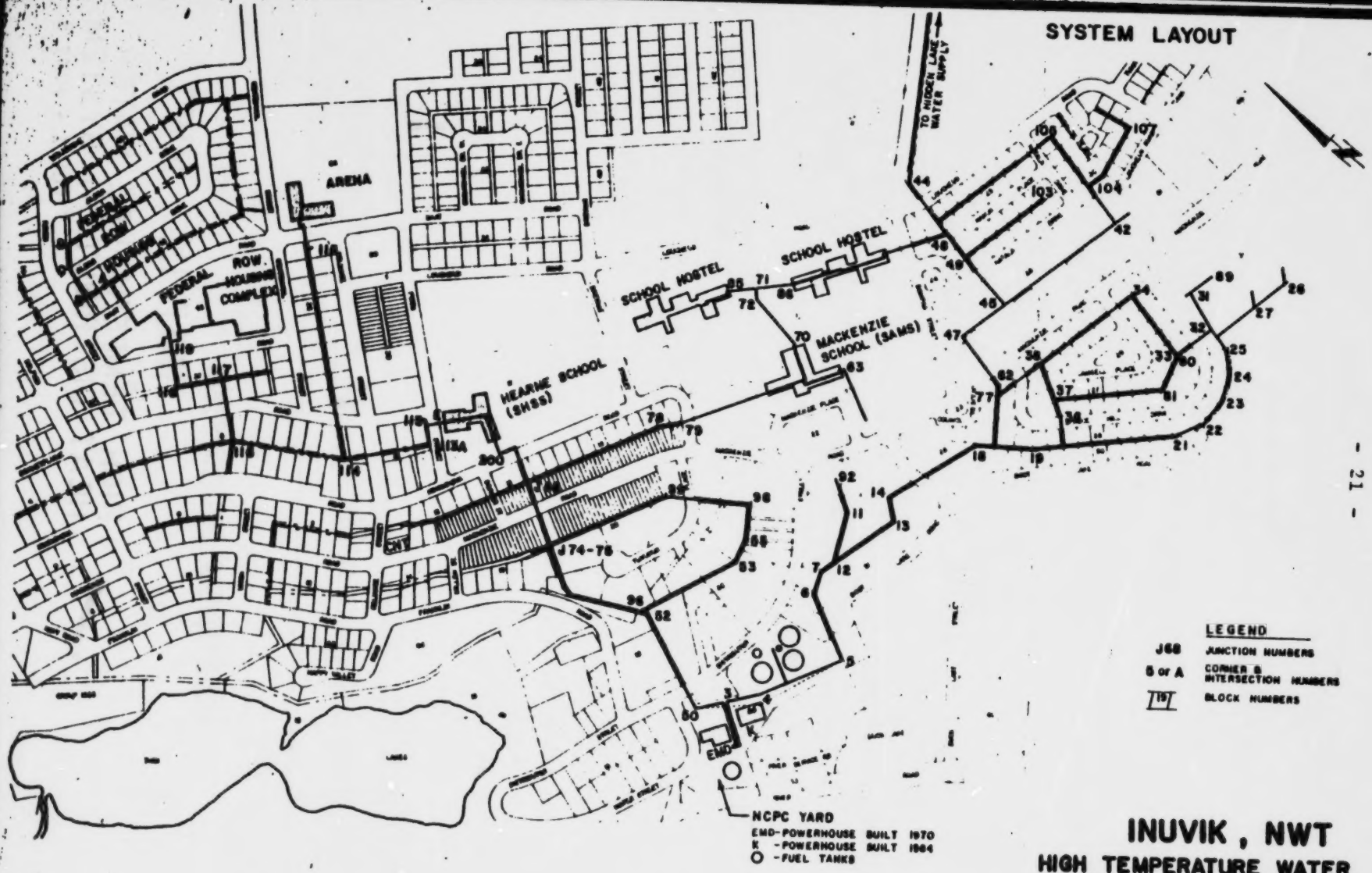
The layout of utilidors carrying HTW piping is shown in Figure 4.

Utilidors

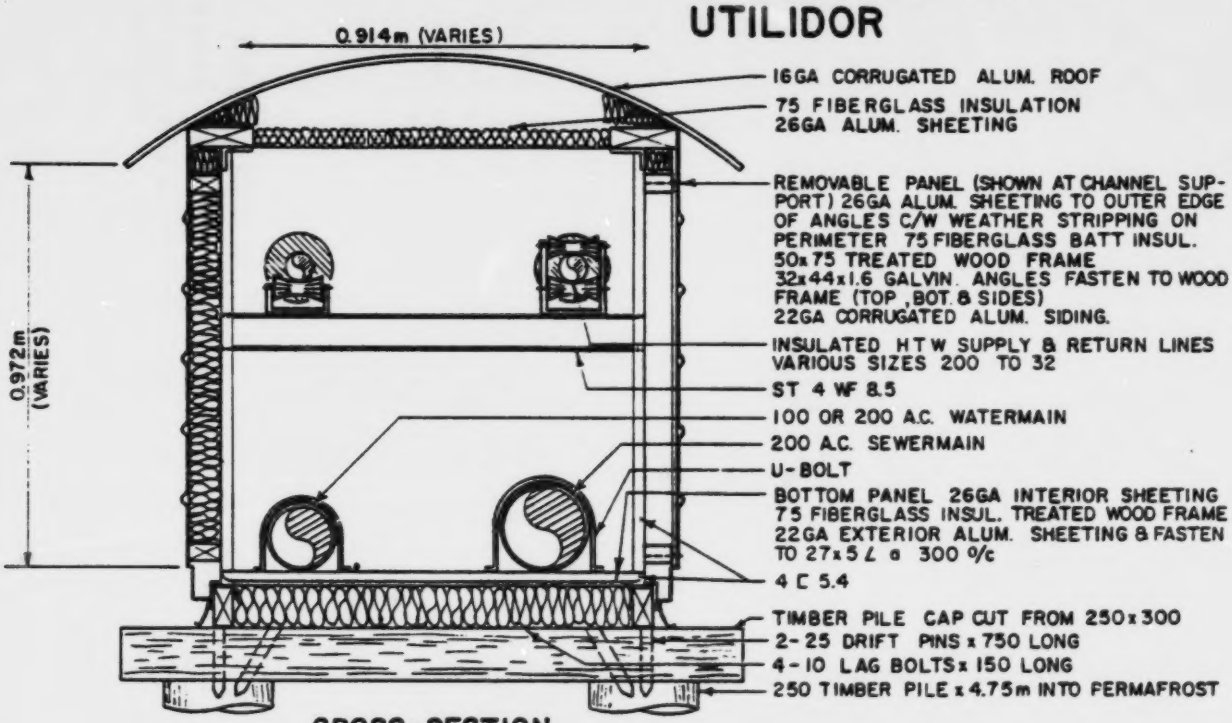
A typical cross-section of a utilidor with HTW piping is shown in Figure 5. As can be seen, the water and sewer mains occupy a lower tier or gallery, and two insulated, welded steel HTW pipes, a supply and a return of the same diameter, occupy an upper level.

All of the utilidor is supported by timber piles and timber pile caps, usually spaced at ten foot centres. On most utilidor runs, two-pile bents (shown) alternate with single piles, the latter type forming a "T" shaped support with the pile cap.

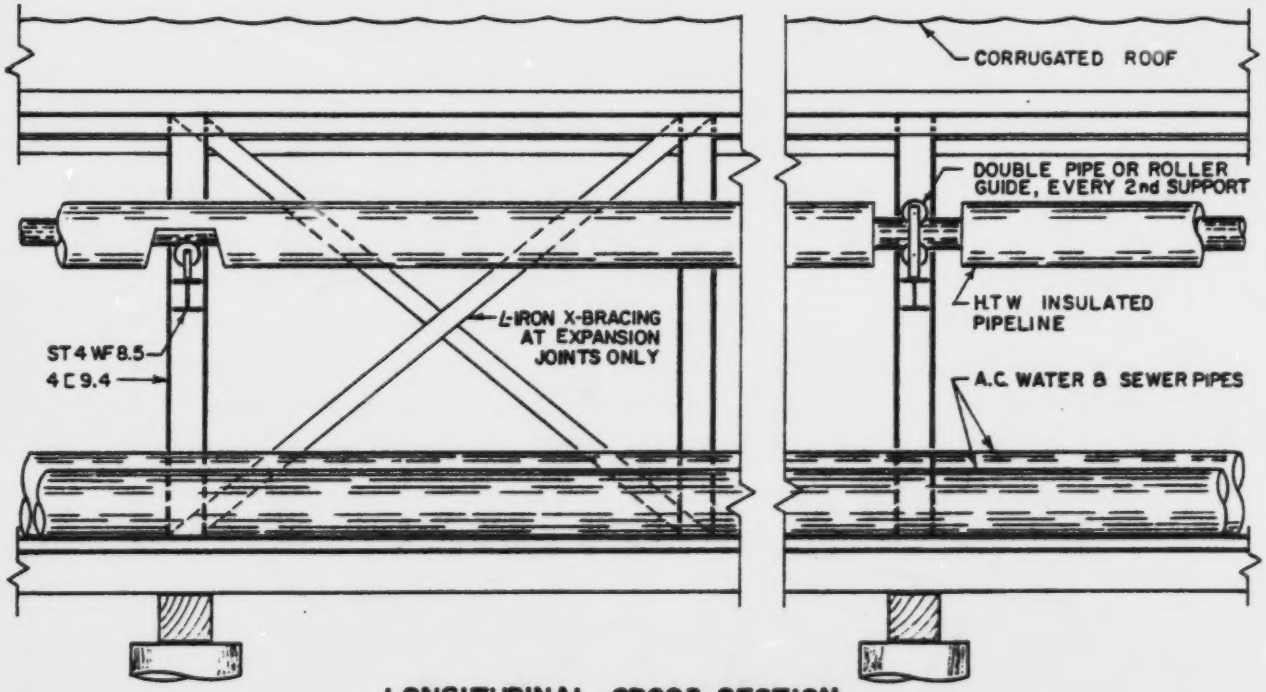
The utilidor box is framed in steel angles and channels, with welded joints. Pipes are carried on steel channel sections, which are an integral part of the steel frame. The top covers of the utilidor box are of formed corrugated metal. The original aluminum ones are easily damaged by (illegal) pedestrian traffic, and nearly half have been replaced by steel. Below the corrugated top, fibreglass batt insulation rests on an interior ceiling liner of plain 26-gauge aluminum, supported by wood stiffeners. Side and bottom panels are wood framed, 3 in thick, sheathed with aluminum on both sides, and insulated with 3 in fibreglass batt. The joint between corrugated top and straight-edged side is closed with a gasket having formed corrugations.


SYSTEM LAYOUT
TO HIDDEN LAKE WATER SUPPLY
ARENA
FEDERAL ROW HOUSING COMPLEX
SCHOOL HOSTEL
SCHOOL HOSTEL
MACKENZIE SCHOOL (SAMS)
HEARNE SCHOOL (SHSS)
J74-75
EMD
NCPC YARD
EMD-POWERHOUSE BUILT 1970
K -POWERHOUSE BUILT 1964
O -FUEL TANKS
LEGEND
J68 JUNCTION NUMBERS
5 or A CORNER & INTERSECTION NUMBERS
[19] BLOCK NUMBERS
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. I FIGURE 4

CROSS SECTION OF UTILIDOR


0.914m (VARIES)
0.972m (VARIES)
16GA CORRUGATED ALUM. ROOF
75 FIBERGLASS INSULATION
26GA ALUM. SHEETING
REMOVABLE PANEL (SHOWN AT CHANNEL SUPPORT) 26GA ALUM. SHEETING TO OUTER EDGE OF ANGLES C/W WEATHER STRIPPING ON PERIMETER 75 FIBERGLASS BATT INSUL. 50x75 TREATED WOOD FRAME 32x44x1.6 GALVIN. ANGLES FASTEN TO WOOD FRAME (TOP, BOT. & SIDES) 22GA CORRUGATED ALUM. SIDING.
INSULATED H.T.W SUPPLY & RETURN LINES VARIOUS SIZES 200 TO 32
ST 4 WF 8.5
100 OR 200 A.C. WATERMAIN
200 A.C. SEWERMAIN
U-BOLT
BOTTOM PANEL 26GA INTERIOR SHEETING 75 FIBERGLASS INSUL. TREATED WOOD FRAME 22GA EXTERIOR ALUM. SHEETING & FASTEN TO 27x5 L @ 300 o/c
4 C 5.4
TIMBER PILE CAP CUT FROM 250x300
2-25 DRIFT PINS x 750 LONG
4-10 LAG BOLTS x 150 LONG
250 TIMBER PILE x 4.75m INTO PERMAFROST

CROSS-SECTION


CORRUGATED ROOF
DOUBLE PIPE OR ROLLER GUIDE, EVERY 2nd SUPPORT
L-IRON X-BRACING AT EXPANSION JOINTS ONLY
ST 4 WF 8.5
4 C 9.4
H.T.W INSULATED PIPELINE
A.C. WATER & SEWER PIPES

LONGITUDINAL CROSS-SECTION

INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. I FIGURE 5

Utilidor side panels are removable. Panels are attached to structural angles by screws, at close centers on all four sides, which fit self-tapped holes. The channels between adjacent panels, and at the top and bottom of each panel, are filled with insulation, and flashed over with aluminum flashing pieces, the lower flashing being specially shaped. Finally, the four butt joints between flashings, at the corners of the panel, are themselves covered by additional flashing pieces. Flashing is attached by wood screws, which match wood framing members in the panel or, in the case of the top flashing, in the utilidor.

Anchor Points

Operating temperatures up to 350°F result in significant linear expansion and contraction of HTW piping, and a need for a system of anchor points and expansion joints.

Corners, pipe main tees and other junction points are all housed and anchored in vaults (which are described in the next section). Additional "line anchors" are provided along utilidor runs at, typically, 150 to 300 foot intervals.

A line anchor consists of a large concrete pile cap, in place of the usual heavy timber one, supported by three or four piles, and a heavy, monolithic concrete block which extends up, filling the utilidor interior, to the underside of the HTW piping. HTW piping is anchored to the top of the block, by means of welded-on pipe collars, which are in turn welded to steel shoes fixed to the concrete by embedded anchor bolts. Water and sewer mains are run through anchor blocks, by means of embedded sections of pipe. A typical line anchor is sketched in Figure 7, which appears later in the report.

Expansion and contraction movements in HTW lines are taken up by expansion joints, installed in the HTW lines between anchor points.

Vaults

The valves and piping crossovers that occur at junction points require more room than a typical utilidor section provides, so these system features are housed in small metal buildings known as "vaults" or "junctions". The largest of these is about 16 feet square. Most have full headroom, discounting obstructions such as overhead pipes.

Like utilidors, vaults are supported well clear of the ground, on piles, to prevent degradation of permafrost and thaw settlement. Many vault piles are steel; some are timber. The usual combined pile cap and floor is of concrete, extended upward where needed to provide pipe anchorage. The building enclosures are insulated metal panels on steel frames. Vaults are windowless, and doors are metal and padlocked. A typical vault is sketched in Figure 6.

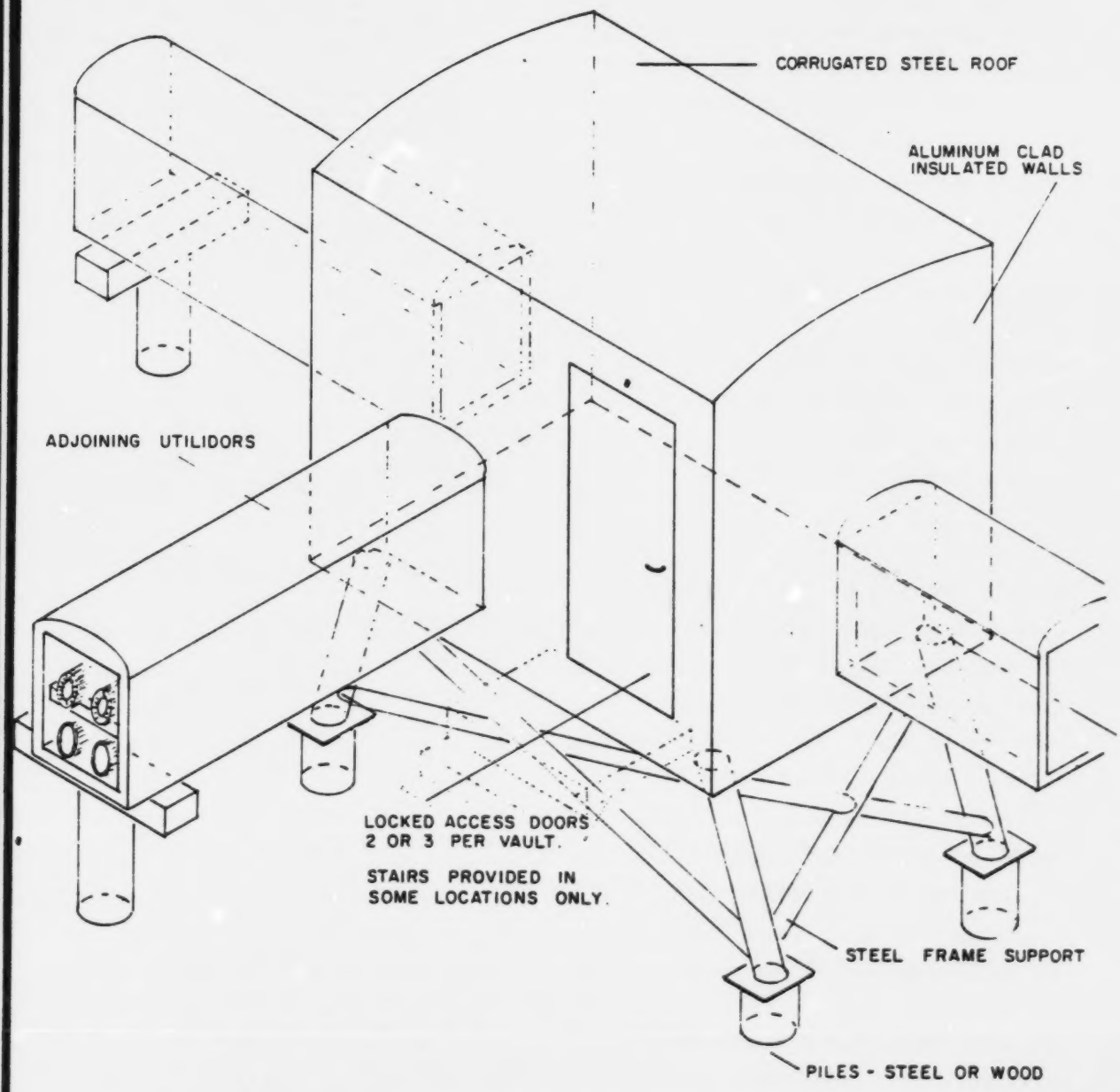
Other Utilidor Designs

Nearly all of the HTW system is run in utilidor of the "original" type, just described.

Exceptions include the 680 foot (210 m) run west through Block 13, from Junction 68 to the CNT building; the small extension south along Block 37 from Junction 117 to the apartment building at the end of the block, and the road crossings under Inuit Road and Natala Drive. Street names, block and junction numbers and other reference points are shown in Figure 4.

The Block 13 extension was built, it is understood, by NCPC maintenance personnel about 1973. The utilidor box is round, of corrugated metal, like culvert piping with bolted joints at mid height along the sides. As far as is known, no drawings of this installation were made, and details of interior layout have not been determined.

TYPICAL UTILIDOR VAULT


CORRUGATED STEEL ROOF
ALUMINUM CLAD INSULATED WALLS
ADJOINING UTILIDORS
LOCKED ACCESS DOORS 2 OR 3 PER VAULT.
STAIRS PROVIDED IN SOME LOCATIONS ONLY.
STEEL FRAME SUPPORT
PILES - STEEL OR WOOD

INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. I FIGURE 6

The Block 37 extension also uses the round split-culvert box design.

All of the main utilidor runs built after 1971 carry water and sewage pipes only, not HTW piping. Some of these follow the half culvert box design, but most use wood frame boxes with insulated plywood top, bottom and side panels. Installation of HTW piping in these would of course involve complete replacement. At most, some of the piling and some of the water and sewer piping might be re-used.

Road Crossings

The road crossings over the original utilidors are small bridges, with concrete abutments and concrete decks. Three more recently built road crossings which carry HTW piping are of a different design, in which HTW (and other utility) pipes are carried in a metal culvert laid in the road bed.

One of these is the service connection from Block 36 to the arena, which passes under Inuit Road. Another is a connection between the supply pipes of two otherwise independant branches of the HTW system, which passes under Natala Drive. The third is the crossing under Berger Street to the west end of Block 13, and the CNT building. Locations are shown in Figure 8, which appears later in the report.

As is described later, the buried culvert arrangement exposes HTW piping to groundwater, and repairs and changes are needed at both locations.

Consumer Connections

Consumer service pipes tee off the HTW supply and return mains, and are carried, along with water and sewer service pipes, to their respective buildings in small utilidors (known as "utilidettes"). Most of the

utilidettes built with the original system resemble the main utilidor in form and construction. Some are long, and some serve more than one building. It is not easy in all cases to decide whether a run of small utilidor should be considered to be a building service connection or a minor branch of the main system.

In most buildings, HTW consumer pipes run to a heat exchanger located in the building crawl space. Shutoff valves are provided at the main tees, and on both sides of the heat exchanger. The selection of the heat exchanger and control method is left to the consumer. As might be expected, a considerable variety exists, somewhat to the disadvantage of both safety and efficiency.

STRUCTURAL ASSESSMENT

Introduction

In the belief that pipe thrust forces due to pressure, expansion and contraction are taken to the ground through the utilidor structure and foundation piles, the original Terms of Reference for the study included a complete structural analysis of the utilidor and its foundation.

In fact, pipe thrusts due to expansion and contraction are kept small, by the use of expansion joints at close intervals. Obviously, thrusts from expansion joints and friction tend to cancel, in the case of a typical line anchor placed between two more or less equal runs of pipe. Furthermore, the utilidor structure to which pipes are anchored is continuous, so thrusts tend to be kept internal within the system. It is believed, therefore, that the horizontal loads transmitted to anchor piles tend to be small. After twenty-five years of service, more or less, the utilidor assembly shows no evidence of structural distress or of horizontal creeping of piles.

In view of this information, reported on completion of the field component of the study, the Study Management Committee directed that the effort to be put into structural analysis be reduced.

The utilidor structure and foundation have been described in the preceding section. Pipe restraints and expansion joints are dealt with in section later on. The objective of the section is to report observations of the current condition of the utilidor, utilidor vaults, and foundations.

Scope of Investigation

A search was made of NCPC's drawing files for details of the construction of utilidor framing; unfortunately, without success; therefore, the discussion in this section is based on field observations.

As described earlier, an exterior inspection was made of all utilidors containing HTW piping, and the utilidor was opened for internal inspection at 54 places. All vaults containing HTW piping were inspected inside and outside.

Piles

The HTW system's 8.6 km of utilidor, approximately 120 anchors and 30 vaults are all carried on pile foundations, and the total number of piles in the system is in the range of 4000.

Almost all piles are timber. Up to 1970, pressure creosoted Douglas fir was used almost exclusively. Most piles installed since then are of hemlock or spruce, probably painted with pentachlorphenol to retard rot.

Vertical loads on piles are relatively light. The weight of utilidor, full pipes and snow carried by a typical bent of one or two piles is less

than two tons. A six-inch diameter spruce pile will carry over ten tons. Piles are larger than 6-inch, and most are of wood species stronger than spruce.

Permafrost has very high load capacity, relative to unfrozen soil, and very good adhesion to timber. The small utilidor loads would be transferred easily, over a much shorter embedment length than must exist, at stresses far below secondary creep range.

Few, if any, utilidor or vault piles have settled over the years. The odd one heaves, and is trimmed by NCPC maintenance personnel. Piles installed in steamed holes are the most heave susceptible, which is why steaming was dropped as a pile installation procedure early in Inuvik's development.

Piles are quite lightly loaded laterally, as well as vertically. As has been mentioned, the proportion of pipe thrust forces due to expansion, contraction and operating pressure which is transferred to the foundation is believed to be small. The same is largely true of forces due to change in momentum in the HTW, water and sewer systems, which in any case are small.

The piles are embedded well into permafrost soil, pass up through the active (seasonally thawed and re-frozen) layer, and up through the air space between ground surface and the pile cap. The section embedded in permafrost will last indefinitely, since it too is permanently frozen. The section above ground is partly protected from summer rain by the utilidor overhead, and frozen during winter, conditions which lead to weathering by drying and frost, but at a slow rate.

The most severely exposed section of pile, by far, is the one passing through the active layer, and conditions are worst around ground surface. Here the wood is moist throughout the warm season and saturated from time

to time by rains, ideal conditions for growth of the microorganisms that destroy wood. The high moisture content also promotes splitting, and breakdown of wood cell walls, by freeze-thaw during spring and fall.

In some places, exposure to water has been increased by use of utilidor rights-of-way as drainage courses, either by original design, or through progressive filling and development of adjacent land.

In spite of twenty-five years exposure to weather, and the unfavourable conditions at ground surface, most of the utilidor piling appears still to be in good condition, and capable of lasting at least as long again. Places where piles do require attention, owing to rot and deterioration of a short section at ground surface, or in a few instances owing to heaving, are the utilidor runs around Natala Drive and Kingalok Place, the run past the Catholic church, and the one behind the RCMP quarters.

To date it has not been necessary to replace or repair piles in the utilidor system. It is not clear how that would be done. Complete replacement would involve dismantling the utilidor to make room for a soil auger, and the same pile locations could not be re-used owing to the difficulty of drilling through the old pile shaft still in the ground. Probably, the existing piles are sound, except for the deteriorated section at ground surface. If that is the case, then it would seem much simpler and much less expensive to design some method of bridging the weak section, or of scarfing a new piece in. The cost of the work will depend greatly on the design.

Pile Caps and Anchor Blocks

The timber pile caps under the utilidor are far stronger than is needed to carry load. They remain in good condition, with little deterioration due to weather.

Concrete pile caps under vaults appear to be in good condition, with the exception of one by the Mackenzie Hotel, which appears to be disintegrating.

Most concrete anchor blocks appear to be in good condition. Exceptions were found in Block 36, where the concrete line anchors 480 ft northeast of junction 114, and 240 ft southwest of junction 115, are disintegrating. The concrete may have been frozen before curing properly. The pipe should be restrained temporarily by other means, and the concrete broken out and replaced.

Utilidor Framing

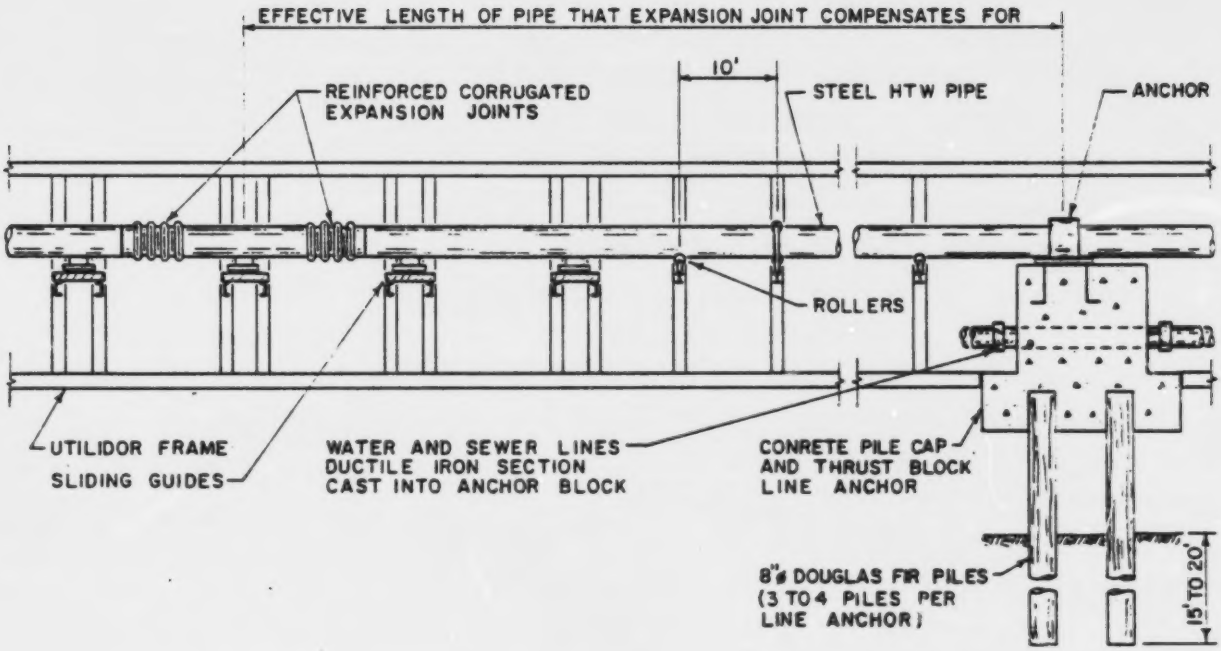
The utilidor framing system of structural steel angles and channels bridges from one pile bent to the next, carrying the weight of utilidor panels and pipes, and snow. It is continuous, so it also provides a continuous foundation bed which tends to carry any unbalanced pipe thrusts, due to expansion and contraction and internal pressure, from anchor to anchor, as diagrammed in Figure 7.

The utilidor framing is strong, rigid, and essentially in original condition. One proof of its freedom from deflection and distortion is the ease with which ten-foot-long side panels are removed and replaced. Any change in shape would make the task very difficult, owing to the large number of existing screw holes that must be lined up to put the panels back on. Structural framing drawings were sought in NCPC's files, unfortunately without success.

Utilidor Panels

Utilidor tops are occasionally dented and bent by foot traffic, and top and side panels are vulnerable to damage by vandalism, minor accidents, and hurried workmanship by utilidette owners or NCPC crews dealing with

TYPICAL HTW PIPE RESTRAINT DIAGRAM


EFFECTIVE LENGTH OF PIPE THAT EXPANSION JOINT COMPENSATES FOR
10'
REINFORCED CORRUGATED EXPANSION JOINTS
STEEL HTW PIPE
ANCHOR
ROLLERS
UTILIDOR FRAME
SLIDING GUIDES
WATER AND SEWER LINES DUCTILE IRON SECTION CAST INTO ANCHOR BLOCK
CONRETE PILE CAP AND THRUST BLOCK LINE ANCHOR
8"ø DOUGLAS FIR PILES (3 TO 4 PILES PER LINE ANCHOR)
15' TO 20'

NOTE:

DIAGRAMMATIC ONLY
NOT TO SCALE
STEEL FRAMING SHOWN CONCEPTUALLY,
NOT PICTORIALLY

INUVIK N.W.T.

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL.I FIGURE 7

emergencies under adverse conditions. In spite of its exposure, the metal box utilidor remains by and large in very good condition, reflecting the energy and commitment of NCPC's staff.

Vault Framing

In the utilidor interiors observed, the prime paint on structural framing is often still in excellent condition. In contrast, the structural steel framing in several vaults is superficially rusted. This may reflect high humidity in vaults due to the inevitable minor leaking from the stem packings of HTW valves. No instance was found in which corrosion had dangerously reduced the strength of a structural section.

Vault Panels

The metal cladding on most vaults is in good condition. One exception is Junction 116, where the vault cladding and adjacent utilidor cladding is torn and dented, and requires some attention. Another is Junction 114, where exterior panels have been damaged by vandals.

Conclusions and Recommendations

The utilidor foundation, structure and enclosure is, in general, in good to excellent condition.

In general, vaults are structurally sound, and cladding is in good condition. Doors are locked, and security appears to be adequate. Access to several vaults is difficult and dangerous, requiring use of a portable ladder, and it is recommended that steps and landings be installed in about five locations.

Most equipment within vaults are in good condition and performing properly. However, pipe insulation in most vaults is badly deteriorated.

Items noted that require maintenance of a routine nature are:

1. Leaking valves, J64, J68, J72, J119, Int A, Int B, Int D.

2. Rollers and/or guides requiring realignment or tightening, J72 (north branch), Int A, Int B (toward C), Int D.

Items noted that require maintenance of a non-routine nature are:

1. Disintegrating concrete pile caps or anchor blocks,

   - Block 20 by Mackenzie Hotel,
   - Bend 114C, Block 36, 480 ft NE J114,
   - Bend 114D, Block 36, 240 ft NE J114,
   - Bend 115C, Block 36, 240 ft SE J115.

All require replacement.

2. Rusting steel building frames, J115 and J119, require power brushing and repainting to protect structural integrity in the long term.

3. Circulation pump frame requires replacement, J116.

4. Vault and utilidor cladding damaged and requires repair, J114 and J116.

5. Utilidor piles deteriorated, requiring repair, Block 21, by Catholic Church.

6. Utilidor piles heaved causing tilted utilidor, and some piles deteriorated, requiring re-levelling and repair, Blocks 25, 26, 30 and surroundings.

Locations are shown in Figure 8.

With respect to the list of non-routine maintenance needs, it is recommended that priority be given to items 1, 5 and 6 and that all be attended to within a 12- to 18-month period.

It is most difficult to estimate the cost of repairs. In all cases the work to be done is relatively minor, but work efficiency will be low due to difficulty of access and the rather fiddly nature of repair work generally. There is also uncertainty as to the method of contracting for needed services, which can have considerable influence on cost.

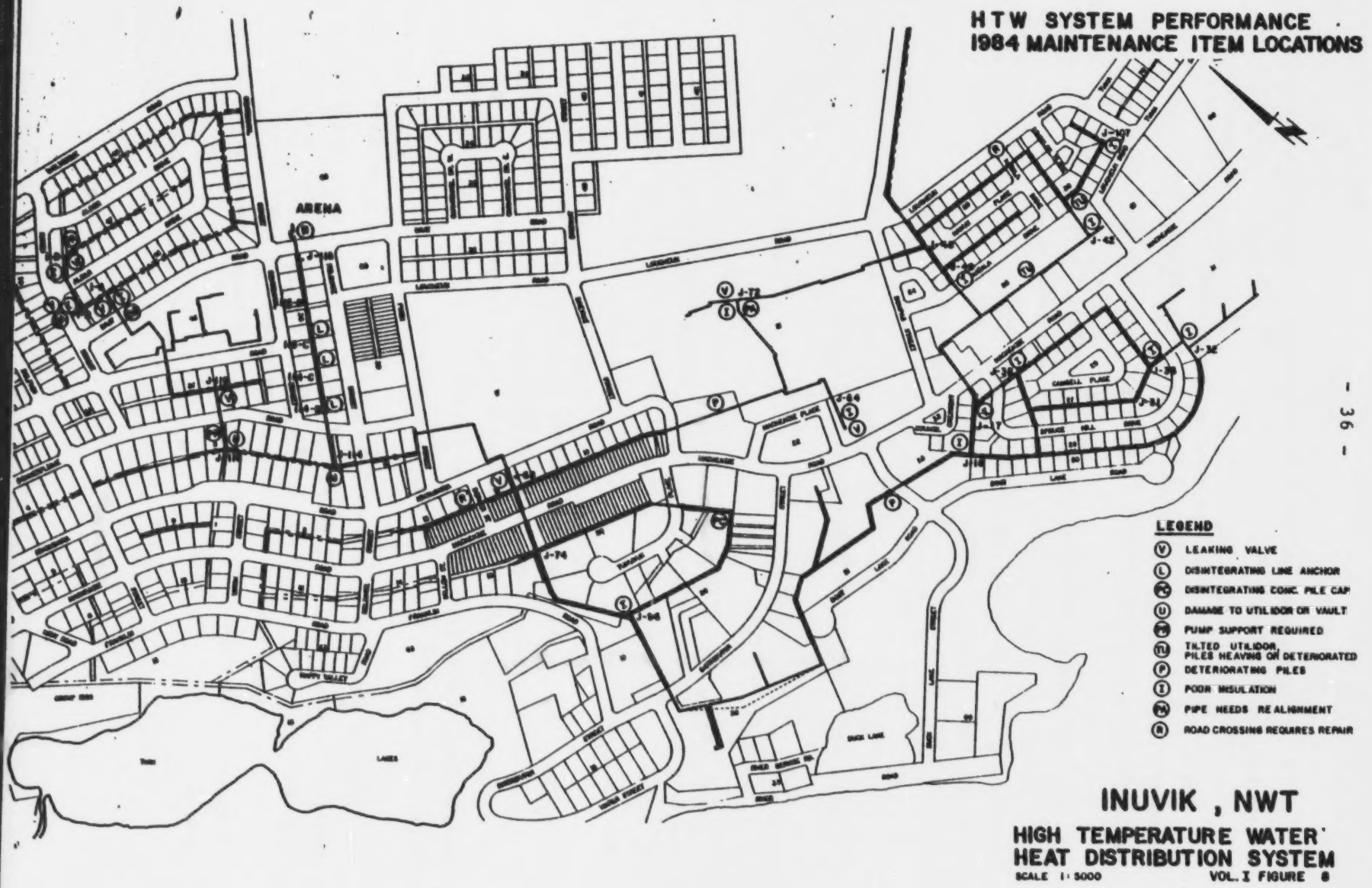
PIPE RESTRAINTS, SUPPORTS AND GUIDES

Introduction

The large temperature range of the HTW system would give rise to tremendous pipe thrust forces, if the pipe were not permitted to expand and contract freely through a system of anchors, moving supports and expansion joints.

The typical spacing between line anchors is 150 to 300 feet, varying according to the actual layout of the utilidor as it makes its way through the townsite. The normal arrangement of expansion joints halves the maximum usual thrust length, to 75 to 150 feet. The longest unbroken run of pipe is nearly 200 feet.

The amount of expansion to be expected in a 150 foot run of pipe due to a temperature rise from, say, ambient of 50°F to supply side operating temperature of 350°F, would be 3.5 in (89 mm). The maximum possible temperature change, between a winter extreme ambient of -60°F to maximum normal operating temperature would give rise to a length change of 4.8 in (120 mm).


HTW SYSTEM PERFORMANCE
1984 MAINTENANCE ITEM LOCATIONS
ARENA
LEGEND
LEAKING VALVE
DISINTEGRATING LINE ANCHOR
DISINTEGRATING CONC. PILE CAP
DAMAGE TO UTILIDOR OR VAULT
PUMP SUPPORT REQUIRED
TILTED UTILIDOR, PILES HEAVING OR DETERIORATED
DETERIORATING PILES
POOR INSULATION
PIPE NEEDS RE ALIGNMENT
ROAD CROSSING REQUIRES REPAIR
INUVIK , NWT
HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. I FIGURE 8

As shown in Figure 7, each run of HTW piping is intended to be free to expand and contract, between an anchor at one end and an expansion joint at the other. In order to avoid friction at supports, which could inhibit movement and, in so doing, draw unwanted loads into the utilidor foundation, the HTW piping is carried on roller supports and, near the expansion joint, on sliding guides. Supports are spaced at ten foot intervals throughtout the system. Every second roller support has a top roller in addition to the bottom (working) one, to keep the pipe from jumping out of the support system in the event of severe waterhammer or some other unusual loading.

Guides are substituted for roller supports at the last two support positions before the expansion joint is reached, to maintain the expansion joints in proper alignment.

The guides used are Bowers Pipe Alignment Guides, which consist of a square base plate which slides in greased grooves, and a rigid attachment which is clamped to the pipes by two U-bolts. The guide allows free movement axially, but resists deflection in any other direction, or rotation about any axis.

The objectives of this part of the study are

- to estimate, generally, the magnitude of thrust forces due to hydraulic pressure, expansion and contraction, and other causes,

- to assess the ability of anchors to resist expected thrust loads, and

- to report observations of the performance, apparent suitability and condition of roller supports and pipe guides.

Scope of Investigation

The six sections which follow report estimates of thrust loads due to hydraulic pressure, change in momentum, friction, gravity and expansion joint spring.

Thrust Due To Hydraulic Pressure

The maximum operating pressure in HTW piping is 286 psi (1.97 MPa), which occurs in the supply side at the powerhouse, the lowest point in the distribution system. The pipes there are also the largest in the system, 8-inch (200 mm).

A pressure of 286 psi acting over a water column face 7.98 inches in diameter (8-inch standard weight steel pipe) would produce a thrust of 14 300 lb (63.6 kN).

Hydraulic pressure thrusts elsewhere in the system are smaller. Pressures are reduced by higher pipe elevation and by friction losses, and pipe diameters are smaller.

Thrust Due To Change In Momentum

The maximum velocities found in the HTW destribution system are in the range of 5 to 6 ft/sec (1.5 to 1.8 m/s). The thrust due to change of momentum in water flowing at 6 ft/sec around a 90 degree bend in 8-inch piping is 45 lb (200 N), negligably small.

Thrust Due To Friction

The friction loads which would resist axial motion in Bowers Guides and roller supports are small. The total drag to be expected over a 120-foot run of pipe is less than 300 lb (1.3 kN): negligably small.

Thrust Due To Gravity

A pipe running up an incline tends to slide downhill. The downhill force, too, must be resisted by the anchorage system. An 8-inch steel pipe 120 feet long, inclined up a 7.5 percent grade, exerts a force of 260 lbs (1.1 kN): neglibably small.

Thrust Due To Expansion Bellows Spring

Full compression of a Flexonics Ltd. 8-inch diameter controlled flexing corrugated expansion joint will generate a reaction in the range of 2000 lb (8.9 kN)*.

Total Force At Anchor

In summary, the principal forces to be resisted at the anchored end of a 120 foot section of 8-inch HTW pipe are

- pressure thrust, up to 14,300 lb (63.6 kN),
- expansion joint reaction, up to 2000 lb (8.9 kN), and
- miscellaneous forces, totalling less than 1000 lb (4.4 kN).

The forces given are for a section of 8-inch pipe with guides and rollers moving freely. Thrusts would be very much higher if for any reason guides or rollers resisted movement.

The sections which follow deal with the adequacy and condition of pipe anchors, roller supports and guides to deal with these forces.

*Based on information from Flexonics Engineering Guide No. 700, p.13 & 22.

Pipe Anchors

Pipes are attached by means of welded gusset plates to steel anchor shoes, which are embedded in concrete and secured by embedded anchor bolts. Most anchor points are individually detailed on Montreal Engineering drawings. It appears that the lengths of gusset plates and the welds attaching gusset plates to the pipe and anchor shoe have been carefully designed, for the loads expected. Anchors have not, with the one exception described below, shown any tendency to deform or fail under any normal loading condition.

The exception to this statement is the utilidor designed by Department of Public Works, Canada, in the early 1970's, to serve the Federal staff housing development in Blocks 45, 46 and 47. Apparently, the loads that would be imposed on anchors by hydraulic pressure in a system containing expansion joints were not fully appreciated. Anchors distorted, and resulted in expansion joints being stretched beyond design limits. This section of the system was rebuilt by SNC Consultants Ltd., under contract to NCPC, in 1983. It appears that the original problems have been eliminated, although it was not possible in all instances to restore original pipe alignment exactly.

A sampling of pipe anchors was viewed in the course of field work for this study, and no sign of deterioration was found.

Pipe Rolls

The HTW piping is supported on manufactured roll supports, similar to Grinnell pattern 277. As mentioned earlier, every second support has an upper, retaining roll in addition to the working one.

Pipe insulation is cut away at the support point, as needed. Cut edges are finished with tape.

Rolls have caused no difficulties over the years, and appear to be in good condition.

Pipe Guides

The use of Bowers Pipe Guides to carry the pipe and to prevent any but the desired axial movement near expansion joints has been described earlier.

Bowers guides appear to be strongly constructed, and seem to be in good condition and performing as intended.

As mentioned earlier, the utilidor box is strong, and provides an adequate foundation for pipe guides and expansion joints.

Guide shoes need to be greased occasionally. It is understood that NCPC does this from time to time, but not, as yet, on a scheduled basis.

Past Failure Events

The only known past failure event in which anchors or supports were involved, is the difficulty in the Federal housing area just mentioned. Repairs have been made, and the incident now has little relevance to the system's future.

The only past failure event involving a Bowers Guide was observed in the summer of 1984. Apparently, the U-bolts clamping the pipe to the guide were not tightened adequately, or worked loose. The pipe slid in one direction, but was held by a sort of friction ratchet action in the other. Over a period of time the guide moved to the limit of its travel, after which continuing pipe expansion and contraction movements progressively bent the structural channel supporting the guide base. Repairs were made shortly after the problem was discovered.

Potential Failure Events

There seems to be little risk of pipe anchors or roll supports breaking, or failing to behave as intended.

It also seems likely that Bowers Guides will continue to serve well. Greasing on a planned, regular basis may be necessary to ensure that guides do not stick. A stuck guide would attempt to resist pipe movement. It would distort under the high resulting load, which in turn could lead to distortion and failure of the expansion joint.

Conclusions and Recommendations

Anchors, roll supports and guides appear to be in good condition, and performing as intended. No recommendations are made, beyond the suggestion that guides (and rollers) be checked and greased, on a scheduled basis.

EXPANSION JOINTS

Introduction

The method by which expansion and contraction in HTW piping is to be dissipated, by means of anchors, rolls, sliding guides and expansion joints, has been described in earlier sections. As mentioned earlier, and as illustrated in Table 2, the length changes to be accommodated are considerable.

TABLE 2

PIPE EXPANSION AND CONTRACTION

Pipe Length (ft)	Range (°F)	Change in Length (In) 50 to 350	-60 to 350	250 to 350
	Change (°F)	300	410	100
50		1.17	1.60	0.39
100		2.34	3.20	0.78
150		3.51	4.80	1.17
200		4.68	6.40	1.56

Notes

(a) The coefficient of linear expansion of steel is 6.5×10^{-6}.

(b) Temperature ranges have been chosen to represent, very roughly, the following conditions:

-60 F, extreme winter cold,

50 F, summer temperature, when the system may be shut down for maintenance,

250 F, approximate minimum return temperature, and

350 F, intended supply temperature.

(c) It is emphasized that Table 2 is presented simply to illustrate the order of magnitude of movement. The temperature ranges and pipe lengths are not representative of any particular operating sequence or any single run of pipe.

The objectives in this section are to describe the selection, performance and current condition of expansion joints, to describe factors affecting system safety and reliability, and to recommend any improvements that seem desirable.

Scope of Investigation

Expansion joints are installed in or adjacent to many vaults, and at approximately 250 locations in main utilidor runs. As mentioned earlier, the field programme for this study included interior examination of every vault containing HTW piping, which in turn included examination of any expansion joints in the vault or visible in the utilidor immediately adjacent. In addition, side panels were removed from utilidors at about fifty expansion joint locations: joints and guides were examined, and measurements were made of joint position and operating temperatures at that moment.

NCPC Regional staff participated in the field work, very kindly contributing considerable time, as well as a truck, tools and their expertise. NCPC staff also described difficulties experienced in the past with expansion joints, apparent trends, and methods of maintenance and repair.

A search was made for alternative expansion joint designs; reported in Part IV of the report.

Expansion Joints

The expansion joints used throughout the system, with the exception of the recently modified Federal housing area, are Flexonics* weld-end, controlled flexing single and double "high corr" stainless steel corrugated bellows units, in diameters to match the run of pipe: 8, 6, 5, 4 and 3. inch.

The joints originally installed in the 2-1/2-inch mains in the Federal housing utilidor were United Flexible of Canada Ltd. 2-1/2-inch corrugated bellows type, fairly similar in design to the Flexonics - UOP joints, but bulkier and lacking a precompression feature. These were replaced, in

*The manufacturer is Flexonics Division of UOP Inc., Brampton, Ontario.

1983, with expansion loops of high pressure flexible stainless steel pipe (hose), specially fabricated by Hydroflex Ltd., of Toronto (SNC, 1983). NCPC considers the Hydroflex loops to be an improvement over the corrugated bellows design. However, they require much more room, and will fit into the utilidor only in the smaller diameters: 2-1/2-inch, and, possibly, 3-inch.

As mentioned earlier, expansion in the 1-1/2" pipe run to Hidden Lake is controlled by pipe offsets, at 20 foot spacing. There are no Flexonics expansion joints smaller than 3-inch.

Sketches of the Flexonics single and double units, and the Hydroflex loop, are shown in Figure 9.

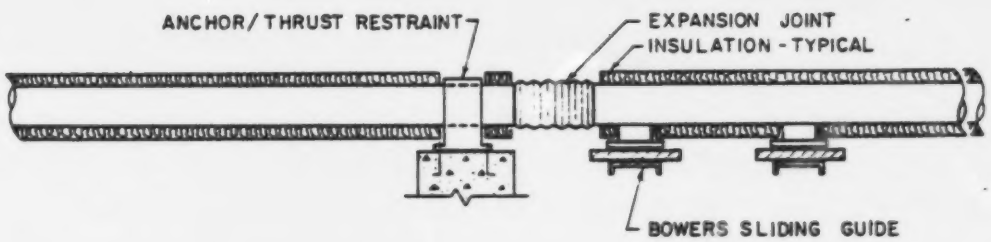
Selection of Flexonics Expansion Joints

Flexonics corrugated-bellows expansion joints are selected by a method described in Flexonics' catalogue. The variables to be considered are diameter, working pressure and temperature, and the amount of axial traverse.

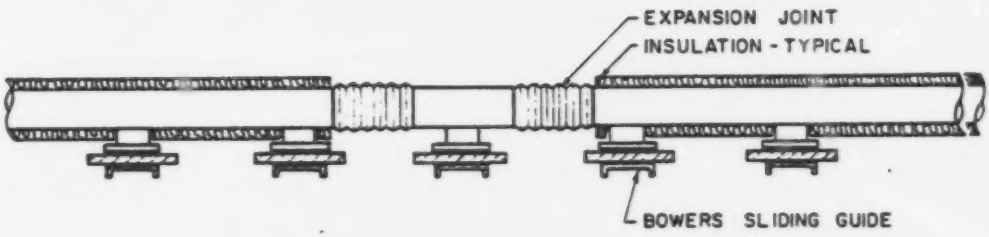
Working pressure and temperature determine the choice of bellows material. The type 304 stainless steel bellows, which has been used throughout the HTW system, has an allowable pressure range from vacuum to 300 psi, and an allowable temperature range from -20° F to 800°F*.

*Special alloys are needed for working temperatures less than -20°F. None of Inuvik's expansion joints are rated for use below that temperature. Naturally, cooling the utilidor to such temperatures would have catastrophic effects on the water distribution system.

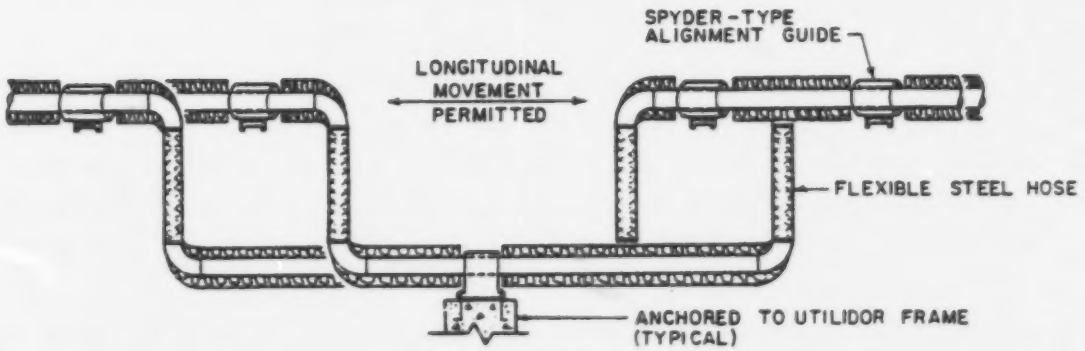
TYPICAL EXPANSION JOINT ARRANGEMENTS



FLEXONICS SINGLE EXPANSION JOINT



FLEXONICS DOUBLE EXPANSION JOINT



HYDROFLEX EXPANSION LOOP

NOTE:
DIAGRAMS ARE SIMPLIFIED

INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE : N.T.S.

VOL.I FIGURE 9

Working pressure determines whether the bellows can be free flexing, or if flexing must be controlled by corrugation neck rings. All of the Flexonics joints in the HTW system are the controlled flexing type, since this feature is required for pressures above 50 psi.

The joint diameter and the axial traverse together determine the number of corrugations needed, and whether a single joint will do the job, or if a dual one is needed.

In order to ensure a safe selection, the calculated traverse length is increased, in the case of controlled-flexing joints, by an amount determined from a graph which is included in Flexonics' design information. The additional length is between 0.7 and 1 inch, for calculated traverse lengths between 1 and 6 inches.

The traverse length, duly increased, and diameter are used to enter a table of joint configurations, and lead directly to the choice of the single or dual type, and the recommended number of corrugations.

Installation of Flexonics Joints.

A Flexonics joint is supplied in its maximum allowable length position. Obviously, before it can be installed, it must be precompressed to correct length corresponding to the temperature of the pipe at the time of installation. For example, consider a joint designed to traverse over a range which corresponds to temperatures from -60°F to +350°F. In order to be installed at an ambient (pipe) temperature of 50°F, it would need to be precompressed to a position about 27 percent of way into its designed traverse. Precompression is achieved by tightening the "grip nuts" on a guide rod; the nuts are fully backed off once the joint has been positioned and welded into the pipeline.

The precompression procedure is explained in some detail in Flexonics' catalogue, and the method of calculating precompression is illustrated.

Performance of Flexonic Joints

The expansion joint is, clearly, the weakest point by far in a system whose only other components are welded steel pipe and the occasional valve. The corrugated bellows needs to be as thin as possible, in order to flex, and in order to minimize stress in the metal due to flexing. Nevertheless, the cyclic loads and stress which expansion joints undergo eventually lead to metal fatigue, and failure.

The metallurgical process of fatigue follows specific course. Ultimately it limits the useful life of every expansion joint bellows to some finite number of cycles. The number survived depends on the properties of the metal, the frequency and magitude of load cycles, and temperature and pressure.

Fatigue is well enough understood that the expected life of an expansion joint can be estimated, if enough is known about the frequency and nature of load cycles, and other determining parameters. The most useful data are continous records of operating temperatures in the pipe, representative of any variation in operating modes, and seasonal effects.

As would be expected, nearly all of the leaks that have occured anywhere in the HTW distribution system to date have been in expansion joint bellows. Considering that the total number of bellows in the system is about 420, the frequency of leaks has actually been quite low. Before 1984, the average rate of expansion joint replacement was about two per year. As might be expected, most replacements have been on the return side of the system, where temperature variation and axial pipe movements are greatest.

No joints required attention in 1983, but the rate of replacement rose abruptly in 1984, to 13. In part this was due to the 1984 field work for the study uncovering eight previously unsuspected leaks, in the sample of about 35 percent of the total number of joints. Locations are shown in Figure 10.

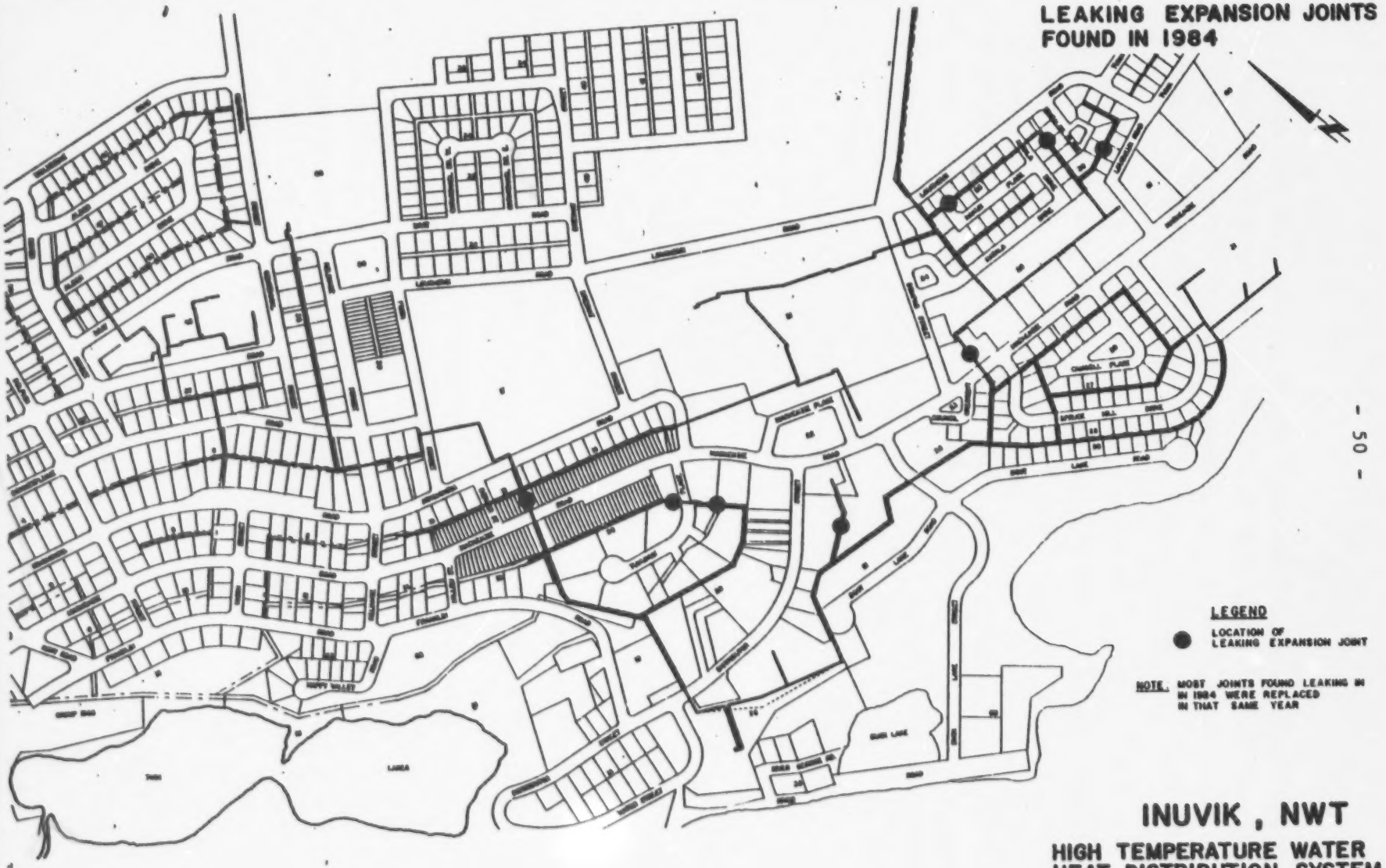
NCPC personnel believe that the anomalous number of joint failures found in 1984 may result from the summer, 1983 shutdown and cooling of the HTW system, while a new boiler was being installed. NCPC avoids cooling the system. The 1983 occurence was the first in four years or longer. As a matter of interest, it was also inadvertent. It had been planned to disconnect and then reconnect only one of the two main branches of the system at a time. Meanwhile, heat and circulation would be maintained throughout the entire system, using existing crossovers. However, activities on the jobsite fell out of step with the planned sequence of cutting and connecting, and the entire system was "down" for 24 hours.

Inspection and Replacement Procedures

To this time, NCPC has conducted inspections of expansion joints and pipe guides, throughout the system, at intervals of some years, not on a scheduled basis.

The usual evidence leading to discovery of a leaking joint is steam issuing from the utilidor, or water dripping out of it, and, in winter, icicles. Residents are quite helpful in reporting to NCPC anything unusual regarding the utilidor. Obviously, very small leaks, which produce only "dry" vapour, go undetected, until they grow.

There are no system base plans which show locations, types and traverse lengths of expansion joints, so NCPC's first step is to open the utilidor, assess the problem, and determine the expansion joint configuation.


LEAKING EXPANSION JOINTS
FOUND IN 1984
LEGEND
LOCATION OF
LEAKING EXPANSION JOINT
NOTE. MOST JOINTS FOUND LEAKING IN
IN 1984 WERE REPLACED
IN THAT SAME YEAR
INUVIK , NWT
HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM
SCALE : 1: 9000
VOL. I FIGURE 10

Maintenance stores are checked for a spare, and an order is placed with Flexonics if necessary.

A leak in a bellows increases slowly over time, but there has been no instance to date of a damaged expansion joint rupturing abruptly. Therefore, NCPC does not change leaking joints during cold weather, to avoid the risk of freezing both water mains and HTW piping, and to avoid the problems of achieving good welds in poor conditions. Once the replacement joint is ready, the change is undertaken as soon as weather is suitable.

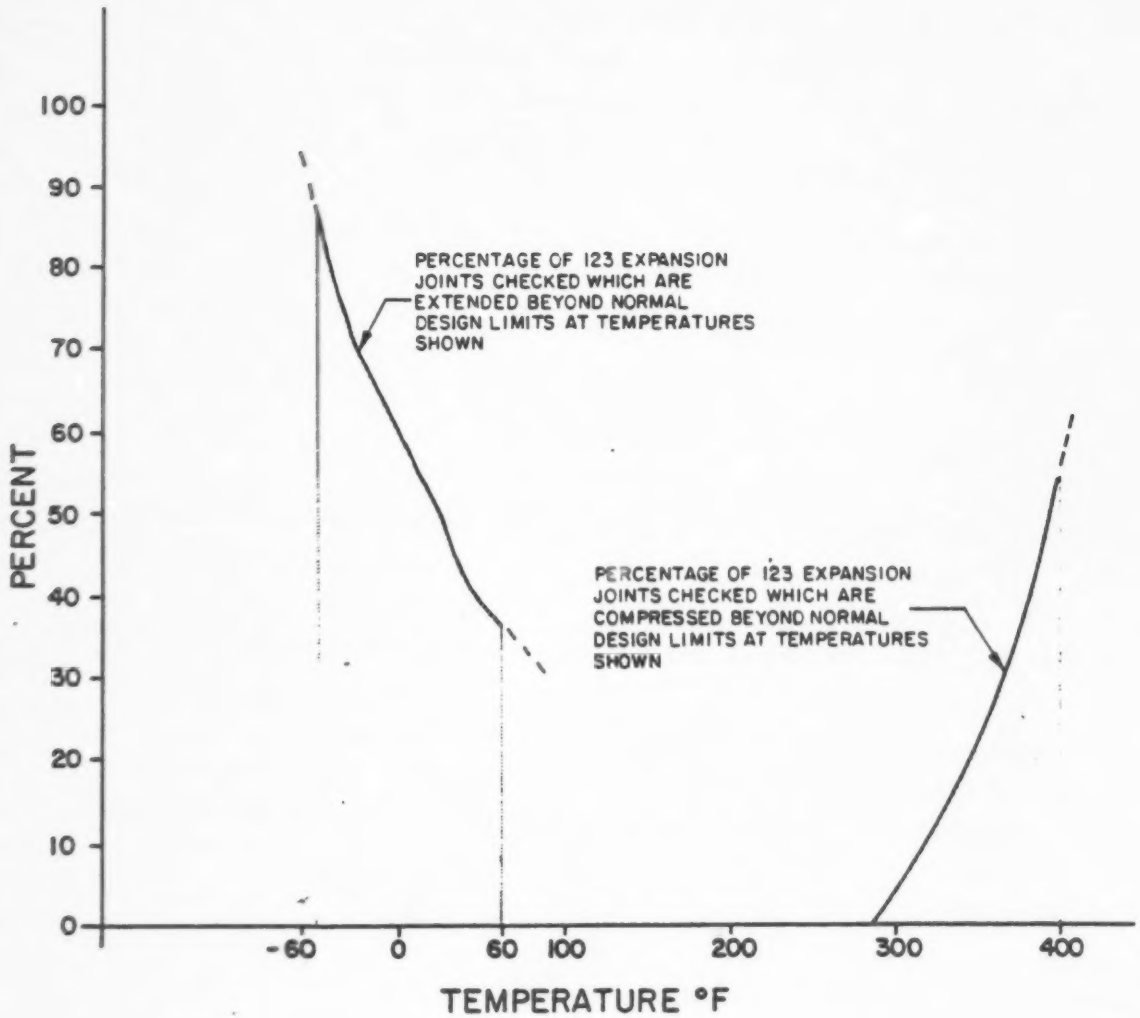
NCPC personnel are completely aware of the need to precompress replacement expansion joints to match pipe position at the time of installation, and of the method of doing that. Precompression is a normal step in their replacement procedure.

Traverse Analysis

Notwithstanding the fairly good performance record of the Flexonics joints, the terms of reference for the study include measurement of the installed position of twenty percent of all expansion joints, and calculation of traverse limits under normal operating conditions and under winter shutdown. In the course of the field work done in the summer of 1984, simultaneous measurements were made of the temperature and traverse position of some 123 individual bellows units. The diameter of each unit, joint configuration, number of corrugations and other observations were also recorded.

Subsequently, the normal traverse limits permitted under Flexonics' design methods were used to calculate the safe minimum and maximum pipe temperature, for each bellows. Findings are summarized in Table 3, and in Figure 11.

EXPANSION JOINT TRAVERSE PERCENTAGE OF JOINTS OVER EXTENDED OR OVER COMPRESSED WITHIN THE TEMPERATURE RANGE -60° F TO 400° F



INUVIK, NWT

HIGH TEMPERATUE WATER HEAT DISTRIBUTION SYSTEM

VOL. I FIGURE 11

TABLE 3

EXPANSION JOINT SAFE TEMPERATURE LIMITS
CALCULATED BY TRAVERSE LIMITS ONLY

Safe Minimum °F	Number	Pcnt	Safe Maximum °F	Number	Pcnt
below -60	21	17	above 400	68	55
-40 to -60	12	10	375 to 400	18	15
-20 to -40	12	10	350 to 375	19	15
0 to -20	10	8	325 to 350	10	8
20 to 0	11	9	300 to 325	7	6
40 to 20	9	7	275 to 300	1	1
60 to 40	3	2	below 275	0	0
above 60	45	37			
	123	100		123	100

Notes:

(a) Type 304 stainless steel bellows should not be used below -20°F.

The analysis indicates, to our surprise at least, that normal summer maintenance shutdowns lasting long enough to cool the system to ambient must pull half or more of the system's expansion joints beyond the manufacturer's recommended limits. Futhermore, up to 15 percent appear to be overcompressed at full (supply) operating temperature of 350°F. The analysis has been submitted to Flexonics for review and comment, among other reasons with a view to ascertaining that there has been no misunderstanding of Flexonics' design method.

It may be significant to the service life of expansion joints in the HTW system, that the system is normally kept running all the time, summer and

winter. The system is shut down, and pipes allowed to cool to ambient temperatures, only very infrequently. The recent increase in the incidence of leaking bellows occurred after the summer, 1983 shutdown for the purpose of installing a new boiler; described earlier.

Past Failure Events

Failures of expansion joint bellows experienced to date have led to leaking, and a need for replacement. There has been no instance in the history of the system of an abrupt, complete failure of a bellows, so failures so far have not directly endangered the system as a whole, or the public.

Leaks are, nevertheless, a source of worry to NCPC, owing to the possibility of stress crack propogation and rupture.

Potential Failure Events

Abrupt rupture of a stress-fatigued expansion joint bellows, possibly one already perforated, could endanger any persons nearby, including maintenance personnel. In cold weather, the resulting loss of circulation would threaten consumers dependent on the HTW system for freeze protection, which includes sections of the water system. The speed with which NCPC could make repairs would depend on the availability of a replacement unit from maintenance stores, and to an extent on prevailing weather conditions.

Conclusions and Recommendations

Of the various components of the HTW main system, expansion joints are the most troublesome, and are the only component in which there has been a recurrent need to install replacements.

The apparent inability of many expansion joints to safely sustain the elongation due to summer cooling, or to cooling to near freezing temperaure, is a source of concern. So is the apparent overcompression in some joints.

The recent rise in the incidence of bellows leaks may be due to

- the complete cooling of the system in the summer of 1983, and resulting large joint movements,
- the increasing incidence of fatigue in an aging system, or
- coincidence.

The second reason, fatigue, would be a source of concern to both the security of the system, and its economics. All of the expansion joints in the system are close to the same age, and share fairly similar stress histories. The cost of replacing, say, ten or fifteen percent of all joints in the system per year, over the next five to ten years, would be considerable.

It is recommended that failed bellows be sent to Flexonics for analysis of the cause of failure and condition of the bellows metal.

CORROSION

Introduction

As has been described earlier, much of the high temperature water distribution piping is twenty years or more old. The pipe is steel. The

question naturally arises, whether the system's safe and useful life may be limited by progressive corrosion.

The objectives of this facet of the study are:

1. Determine the effects of corrosion in HTW distribution piping to date.

2. Estimate the remaining useful life of the distribution system, if it is limited by progressive corrosion.

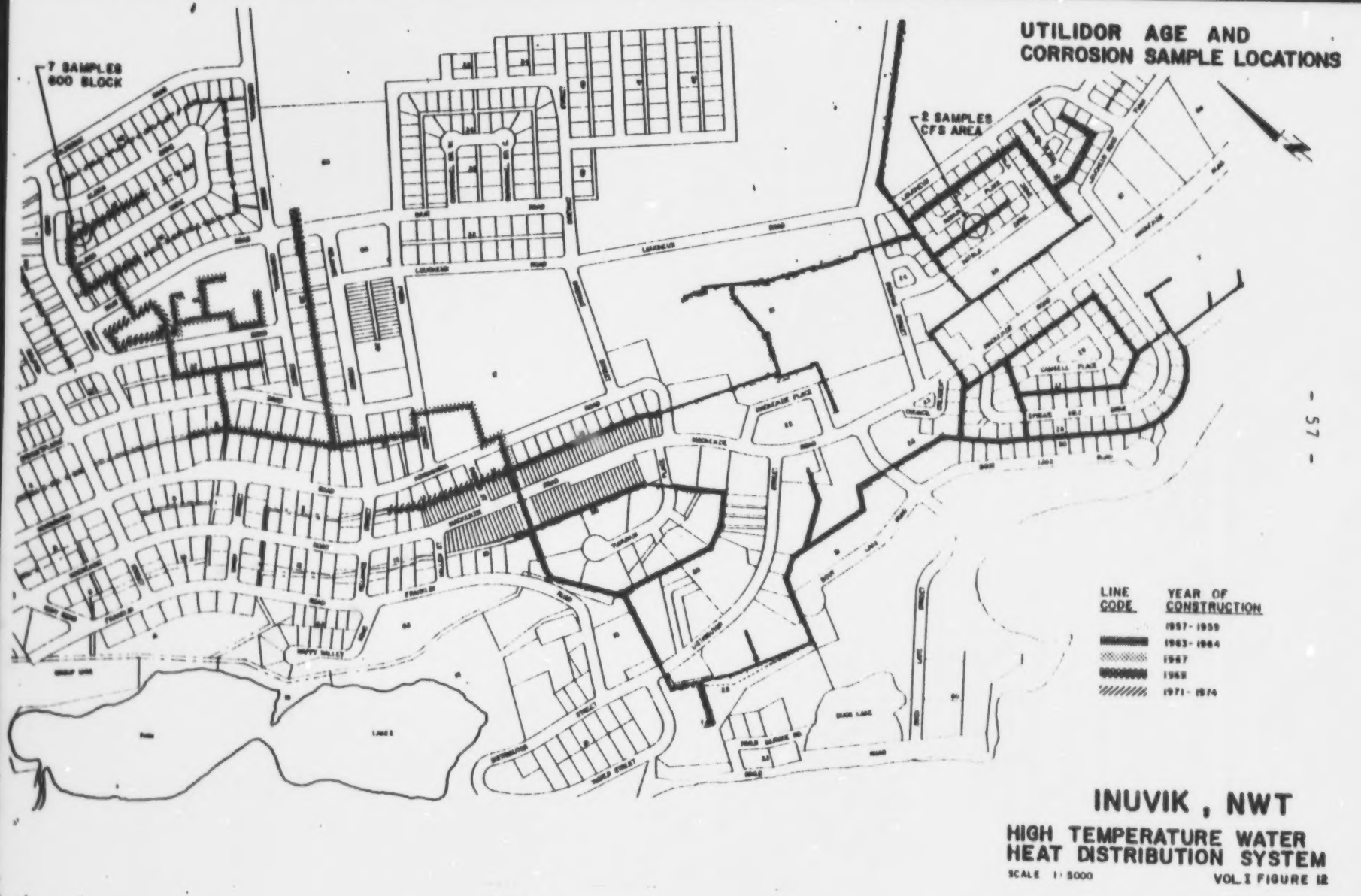
3. Recommend locations for installaton of corrosion monitoring coupons.

Scope of Investigation

Nine pipe examples were provided by the Department of Public Works. It is understood that these were collected by NCPC personnel, at times when repairs or changes were being made to the system.

The locations from which the samples were taken, and the dates on which they were cut out, insofar as these could be determined, are shown in Figure 12. Figure 12 also shows the approximate construction year of each branch of the HTW system.

The nine samples do not provide representative coverage of the entire distribution system. However, as discussed later, they show no detectable evidence of corrosion. It is considered, therefore, that the fairly substantial expense (and some risk) involved in shutting down sections of the system and taking additional samples would not be justified, and no additional sampling has been done.


UTILIDOR AGE AND
CORROSION SAMPLE LOCATIONS
7 SAMPLES
600 BLOCK
2 SAMPLES
CFS AREA
LINE CODE
YEAR OF CONSTRUCTION
1957 - 1959
1963 - 1964
1967
1968
1971 - 1974
INUVIK , NWT
HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. I FIGURE 12

As a matter of interest, ultrasonic pipe wall thickness measuring equipment is portable and can be used in the field. Further testing could be done on pipes in situ, without interruption of service, if at any time that appears to be desirable.

The nine samples were examined visually by Mr. R.J. Kronstedt, M.S., P.Eng., a metallurgist of Associated Kellogg Ltd.'s (AKL's) staff. Wall thicknesses were measured, ultrasonically, by Hanson Materials Engineering (Western) Ltd. AKL's report and Hanson's are summarized below.

A search was made for records of the original wall thicknesses of the pipes from which the samples were taken, in NCPC's head office and regional office files. As explained later, it has not been possible to determine original wall thickness.

Service Conditions Affecting Corrosion

The HTW piping is enclosed in utilidors, protected from rain. Within utilidors, it is nearly always positioned above water and sewage piping, where it is also more or less clear of any water leaking from those systems. Finally, the temperature of the HTW piping and its insulation remain far above the dew point, except on the very rare occasions that the system is shut down. As would be expected, no corrosion has been found on the exterior of the HTW piping in the ordinary runs of utilidor where these conditions prevail.

Exterior corrosion is known to be taking place in one specific location at least, that being the crossing to the Arena under Inuit Road. The HTW piping is carried through the road base in a culvert, along with water and sewer lines. The culvert evidently was installed to protect the piping from, among other things, water. Contrary to plan, the culvert also serves as a minor drainage installation. Steam has been seen rising from

its ends for some years, no doubt produced from the saturated insulation of the HTW piping. NCPC recently inspected the HTW pipes and found them to be in need of immediate replacement.

The culvert-enclosed crossing under Natala Drive is another location where HTW piping may be wet, and corroded. Currently, the single HTW pipe in this crossing, which is a connection between the supply pipes of two otherwise independant branches of the system, is out of service, pending repairs to be done in the summer of 1985. Service to consumers either side of the crossing is not affected.

The presence and rate of interior corrosion is a function of the chemistry of the circulating water. Chemistry is in turn affected by temperature, which varies throughout the system.

Inuvik draws water from East Channel in winter, from October or November, to the end of April. From May until October or November, water is taken from Hidden Lake. Hidden Lake's catchment is very small, so all of the water abstracted is replaced by pumping from Lake B, in summer months, and from East Channel during the winter.

East Channel's wintertime water is moderately hard, running between 100 and 140 mg/L as calcium carbonate, and pH is 8.0 $\pm$ 0.1. The water taken from Hidden Lake is very soft, between 5 and 10 mg/L calcium carbonate, and pH is 7.5. Langelier indices have not been calculated, but the lake water obviously is fairly aggressive.

Apart from corrosion, which results from electrochemical effects, pipe may be eroded by the mechanical abrasion of flow. Flow restrictions and bends, where there are high velocities or large changes in momentum, are the more vulnerable locations.

Erosion does not usually occur at flow velocities below 10 ft/sec (3.3 m/s). Flow velocities in the HTW pipe mains are modest, generally being less than 5 to 6 ft/sec (1.5 to 1.8 m/s). Erosion damage would therefore not be expected. This has not been confirmed by a sampling program, owing to the disruptive system shutdown that would be needed to do that.

Existing Corrosion Protection Practice

Corrosion in the distribution system is prevented by removal of oxygen, and by control of the pH of the circulating water. NCPC retains Perolin-Bird Archer, of Cobourg, Ontario, a company well known for boiler feedwater conditioning, to conduct tests every few years and recommend conditioning chemicals and dosage levels.

Oxygen is removed by addition of sodium sulphite, in quantities sufficient to maintain SO_3 at 30 to 60 mg/L in the water returned to the powerhouse. As mentioned earlier, the HTW system's expansion tank is capped with nitrogen.

Caustic soda (NaOH) is used to increase pH, to the range 9.5 to 10.

It is noteworthy that no conditioners are used that would be toxic in the event of a minor cross-connection occurring between the HTW and domestic water systems. In particular, there is no use of polyphosphate or chromate conditioners.*

*Mr. Dave Musselwhite, personal communication

Assessment of Pipe Samples

Pipe samples were examined visually for signs of corrosion. An attempt was also made to determine if wall thickness has been reduced, over the years, by corrosion or erosion. Visual observations were described in Mr. Kronstedt's report dated October 10, 1984:

> "A visual examination of the nine pipe coupons reveals very little internal corrosion has occurred. Any corrosion that has occurred appears to be uniform as no localized pitting was observed. On several coupons, the internal flash of the longitudinal weld seam is quite prominent. This would indicate that very slight corrosive attack has occurred. Also, on the two butt welded coupons, the internal projection of the weld is prominent and the areas adjacent to the weld appear flat. Additionally, in the local areas of incomplete penetration of the butt welds, the edges of the pipes appear to have sharp edges. These observations support the premise of very slight corrosive attack."

It would be of interest to know if pipe wall thicknesses have been reduced by uniform corrosion or erosion over the years, and, if so, to know the rate of loss.

Unfortunately, the original pipe wall thickness cannot be determined. It is fairly certain, considering both the pressure range to be designed for and the existing wall thickness, that the HTW piping is schedule 40. This is supported by the one reference to pipe specifications that a search of NCPC's files has turned up. Knowing the pipe's schedule is not enough, however, because of the fairly broad thickness tolerance allowed in the standards which govern the manufacture of steel pipe. For example, the current editions of ASTM A53 and API-5L allow the pipe wall to be as much as 20 percent greater, and up to 12.5 percent less than the stated nominal thickness. Obviously, even knowledge of the original pipe specification

gives only a general indication of actual wall thickness at the time of installation.

Hanson Testing mesured the wall thickness of each pipe in the sample at six locations, 60 degrees apart radially and spread longitudinally as well. Two coupons (No. 5 and 7) included welded joints, so each of these provided two pieces of pipe ("a" and "b") for measurement. Hansons' measurements are summarized in Table 4. Table 4 also shows the wall thickness requirements of ASTM A53 for Schedule 40 pipe.

TABLE 4

PIPE WALL THICKNESS MEASUREMENTS

Sample	Dia.	Age	Measured Thickness			Specified Thickness		
			Max.	Avg.	Min.	Max.	Nominal	Min.
	in	yrs	in	in	in			
1	2.5	11	.200	.200	.200	.244	.203	.178
2	2.5	11	.200	.199	.195	.244	.203	.178
3	2.5	11	.210	.207	.200	.244	.203	.178
4	2.5	11	.230	.219	.210	.244	.203	.178
5a	3	11	.220	.213	.210	.259	.216	.189
5b	3	11	.220	.218	.215	.259	.216	.189
6	2.5	11	.225	.218	.210	.244	.203	.178
7a	3	11	.215	.211	.210	.259	.216	.189
7b	3	11	.225	.221	.220	.259	.216	.189
8	1.5	24	.160	.147	.135	.174	.145	.127
9	1.5	24	.160	.153	.145	.174	.145	.127

Notes:

(a) Age is the approximate time from installation to sampling.

(b) Accuracy and precision of ultrasonic thickness measurements are both in the range .003 to .005 in. Hansons' measurements were all reported to the nearest .005 in.

(c) Specified thickness is based on American National Standard Code for Pressure Piping ASTM A53, Power Piping.

In his report, Mr. Kronstedt noted that

> "Based on the wall thickness measurements reported by Hanson Materials Engineering Ltd., it is reasonable to assume that all pipe was supplied as standard weight pipe..... one can observe that reported values are very close and in some cases greater than required by ASTM. The overage could be attributed to mill tolerance".

It is also significant to record that NCPC operations staff* report that they have never seen evidence of pipe corrosion, during maintenance operations involving cutting of pipe or disassembly.

Corrosion Rate and Lifespan

Mr. Kronstedt's conclusion that "it appears that the corrosive effects on the pipe coupons has been slight" is supported by all evidence found in the course of the study.

Conclusions and Recommendations

The rate of corrosion experienced since the HTW system was built is negligible. If past success with water conditioning continues, corrosion will have no effect on the useful life of the system in the foreseeable future.

Besides being effective, existing water treatment practise poses no risk to the public should a cross-connection ever occur between the HTW and domestic water systems.

*Mr. Bev Woslyng (now retired) and Mr. G. Red Cheyney, in discussions.

PASSAGE THROUGH BUILDINGS

Introduction

High temperature water mains pass through the crawl spaces of Sir Alexander MacKenzie School and its associated hostels, beneath Samuel Hearne High School and the Eskimo Inn, and through the crawl spaces of the Federal row housing units in Blocks 45, 46 and 47. Locations are shown in Figure 13.

The Government wishes to know if this arrangement could threaten the safety of people in the buildings, including NCPC and building operations and maintenance personnel, or the security of the HTW system itself.

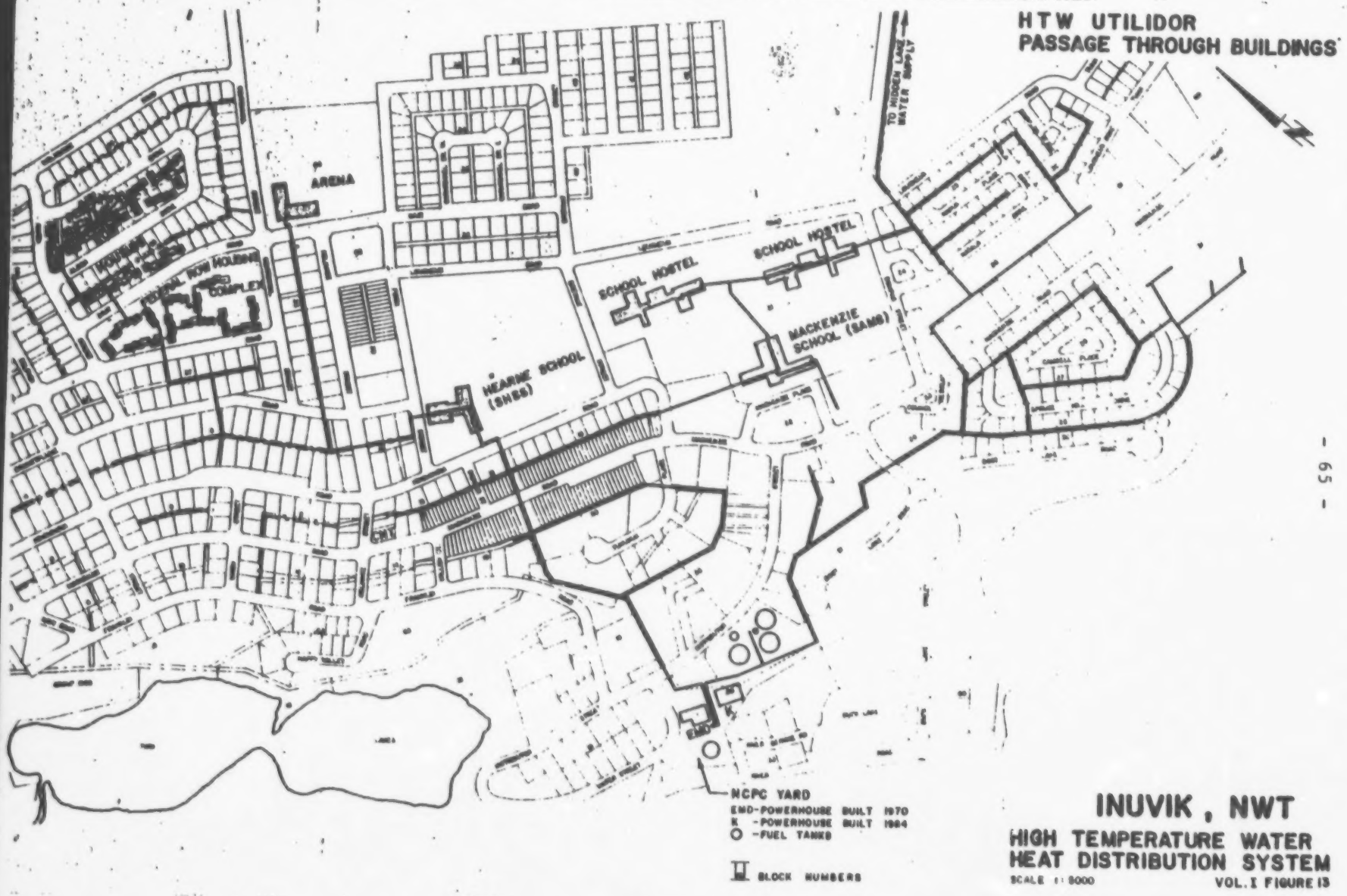
Water carried in the HTW system is as much as 140 F above its sea level boiling temperature. If a pipe break or expansion joint bellows rupture were to abruptly release the high temperature water, some of it would flash explosively into steam, and the rest would be sprayed about as scalding water. The potential for damage and injury is obvious.

The Government's second concern is for the security of the system, especially in the event of a serious fire occurring in one of the buildings it passes through, or under.

Scope of Investigation

A number of crawl spaces containing HTW piping were inspected. The sample was representative of different building types.

NCPC personnel provided information on past problems with HTW lines in crawl spaces, and advice regarding potential difficulties. They also assisted in arranging access to buildings.


HTW UTILIDOR
PASSAGE THROUGH BUILDINGS
TO HIDDEN LAKE WATER SUPPLY
ARENA
SCHOOL HOSTEL
SCHOOL HOSTEL
MACKENZIE SCHOOL (SAM8)
HEARNE SCHOOL (SHS6)
NCPC YARD
END-POWERHOUSE BUILT 1970
K -POWERHOUSE BUILT 1984
O -FUEL TANKS
BLOCK NUMBERS
INUVIK , NWT
HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. I FIGURE 13

Observations

All of the building crawl spaces observed are quite spacious, horizontally if not vertically. The enclosed volume is reasonably large. Furthermore, they are reasonably well separated from the rest of the building, by the intervening main floor. It is our expectation that a release of high temperature water into a crawl space would present no sudden risk to people in the living or classroom spaces above. Humidity and temperature would rise, probably to uncomfortable levels, but it is believed that this would happen slowly enough that there would be ample time to give the alarm and clear the building.

It could be a much more serious matter for any maintenance personnel caught in a crawl space by an HTW accident. Distances to exits are long, and movement through crawl spaces, partly obstructed by pipes and tools, is slow. Suffocation is a real danger, in addition to burns.

As described earlier, expansion joints are somewhat vulnerable to failure, while ordinary runs of pipe are, on the other hand, strong and rugged. Crawl spaces are much wider than the utilidor. The system's designers made use of the extra space to accommodate expansion loops of pipe, eliminating the need for expansion joints, and freeing crawl spaces from the most troublesome of the HTW system's usual list of components. Stuck valves in crawl spaces still remain an occasional problem, potentially dangerous to persons working on them.

A very severe fire in a building carrying HTW mains quite probably would put the mains out of service. The mains through Alexander MacKenzie School and its hostels are looped, so a damaged zone could be isolated with little or no effect on adjacent consumers. The mains below Samuel Hearne School, however are the sole route to Blocks 8, 36, 37, 45, 46 and 47. A serious fire there would leave a large number of residential

consumers without heat, including the entire Federal row housing complex. It would also leave a number of blocks without water, since water system valves are not arranged for isolation of the school utilidor run.

Freeze protection in the water distribution system along Inuvik's north side would be impaired as well.

A bad fire in certain of the units of the Federal housing complex could cut service to certain other units.

The Eskimo Inn, on the other hand, is separated from the utilidor by what amounts to a concrete bridge built between the two. The utilidor is well protected. In any case, it is also looped, so a break at the Eskimo Inn would not affect other consumers.

Conclusions and Recommendations

Having the utilidor run through building crawl spaces does not appear to present any unusual risk to occupants.

There is some danger to maintenance personnel working in crawl spaces on active HTW lines, or on valved-off lines which still contain superheated water. As is described in the next section, there have been one or two instances in the past of HTW system valve stems failing, when attempts were made to operate them. Any accidental release of high temperature water is extremely dangerous to anyone nearby. The danger of suffocation is added to the risk of severe burns, in a confined space.

A serous fire in a building carrying HTW mains could damage or destroy a section of the system. The only buildings in which fire might have serious consequences for other consumers are Samuel Hearne School and, to a lesser extent, certain units in the Federal housing complex.

The costs and possible benefits of looping the system around Samuel Hearne School are discussed in a later section.

Developers of commercial and multifamily residential lands occassionally request permission to encroach into utilidor easements and rights-of-way, or to build above utilidor lands or the utilidor itself. It is recommended that a policy covering such questions be developed jointly by NCPC, the Government of the Northwest Territories and the Town of Inuvik. The policy should include any appropriate standards for clearances, access, fire protection and other matters affecting design.

DISTRIBUTION SYSTEM MONITORS AND CONTROLS

Introduction

Day to day monitoring and control of the HTW system is done entirely from the powerhouse. The distribution system itself contains valves and crossovers for use in isolating sectors or branches, and crossovers which can be used to maintain flow during partial shutdowns.

This section reports on the adequacy of these arrangements.

Scope of Investiagation

Facilities at the powerhouse and in vaults were observed. NCPC personnel provided information and comments.

Monitors

Distribution system pressure, and supply and return water temperatures are monitored at the powerhouse. Supply and return temperatures are recorded

continuously, on seven-day circular charts. Pressure and temperature gauges are not normally installed in vaults, or at any other places in the distribution system.

Controls

The control of heat supply has been described earlier.

Circulation is driven at all times by one circulation pump.

Isolating valves are provided on all supply and return mains at branch junctions. Isolating valves are also provided on supply and return mains at both ends of runs through building crawl spaces, and at a sufficient number of other locations that the system can be broken up into reasonably short segments. Most (but not necessarily all) valve locations are shown on 1:1000 system base plans, prepared in the course of the study.*

Valves appear to be in good condition, generally. Valve packings are always a source of slight leakage. Leaking high temperature water evaporates and deposits sodium hydroxide and other salts around valve stems. Accumulated deposits both corrode the valves and "freeze" the stems in their normal position, open or closed, rendering them inoperable when needed. Accordingly, NCPC attempts to service main system valves every year or two.

*Completion of base plans was added to the work of the study after field work was under way. The base plans were compiled from construction drawings and earlier base plans available from NCPC's files. It was found, later, that some valves are not recorded on existing plans. Known ommissions have been added to the new plans; others may still have been overlooked.

A number of vaults also contain crossovers between supply and return mains, normally valved off, which can be used to maintain flow during partial shutdowns.

Discussion

The pressure and temperature information available at the powerhouse is sufficient for routine operation of the distribution system.

NCPC personnel also consider that the number of shutoff valves placed throughout the distribution system is sufficient to isolate any section in which a problem arises, and confine the incovenience to a reasonably small number of consumers. A review of system base plans has not uncovered any locations where there would seem to be a particular need for additional valves.

The HTW distribution system has multiple loops. Consequently, its flow patterns are complex and not well known. Furthermore, flow patterns are constantly influenced by changes in flow through consumers' heat exchangers, in response to consumers' control devices.

Suncord Engineering Ltd.'s computer program Hydrotherm II models the HTW system's hydraulic and thermal flows. Additional temperature monitoring on both supply and return mains at system branch points would help to confirm and refine the accuracy of that model.

Conclusions and Recommendations

Existing distribution system monitors are adequate for normal system operation, and detection of trouble.

Existing distribution system controls are adequate for the purposes of preventative maintenance and major repairs, when needed. They are also sufficient for confining trouble to reasonably small sections of the system.

Additional temperature monitors on supply and return lines at branch points could help in determining hydraulic and heat flows in the system.

PART III
CONSUMERS

Part I of the report dealt with central heat generation facilities, and Part II with HTW distribution network. Part III deals with consumers' facilities for taking heat from the distribution mains.

The topics addressed include

- division of ownership and responsibility, and implications,
- consumer equipment design, and standards, and
- safety and reliability.

OWNERSHIP AND RESPONSIBILITY

Introduction

A question arose in the mid-1970's, as to whether Inuvik's various utilities systems are owned by the Federal Government, NCPC, the Government of the Northwest Territories or the Town of Inuvik. It is understood that the matter of ownership of the HTW system has not been resolved.

NCPC continues to operate and maintain the distribution system.

The matter of ownership of consumers' connections to the HTW system has not been at issue. NCPC's position, which seems to be accepted generally, is that the consumer is responsible for everything from the main taps out. Shutoff valves on both supply and return service lines are required at the main. NCPC also recommends that consumers provide additional shutoffs on

both sides of the heat exchanger, and a normally closed heat exchanger bypass outside those valves. Most if not all consumers comply. Consumers are responsible to maintain their own facilities.

Discussion

In our view, there would be significant benefits in placing responsibility for operation and maintenance of all facilities through which high temperature water flows, with a single agency. It might also be advantageous to the system as a whole if ownership of the distribution system included ownership of consumer connections, up to and including the heat exchangers.

The first consideration is standardization of design, and assurance of good design standards. To illustrate, new consumers coming on to the system have, in some cases, chosen to undersize heat exchangers to save capital cost. Undersizing is compensated by increasing the flow of high temperature water through the exchanger. Thus the consumer draws excessive amounts of high temperaure water from the supply main, and sends it to return at excessively high temperatures, resulting in increased heat losses from the utilidor, increased circulation pumping cost and inefficient boiler operation.

Another example of misplaced economy is in control systems. The cheapest systems once avoided the cost of an automatic modulating valve controlled from a building thermostat, by providing instead a manual on-off valve. The setting for summer was "off" and for winter "on". The further refinement of regulating room temperature was achieved by opening and closing windows. There are now no control systems as primitive as the one described heating buildings, but some are still used to heat utilidettes.

A related reason for consolidating control of the total system is standardization of heat exchangers, shutoff valves and, especially,

control valves. High temperature water is a demanding class of service for valves. NCPC has found by long experience that the products of some manufacurers stand up well, while the corresponding products of others do not. Because control valve failures are one of the system's recurrent nuisances, NPC has made a point of advising prospective new customers as to whose valves to install and whose to avoid. Nevertheless, valves well known to be prone to early failure still appear. This has been particularly true on public funded projects, where purchase of materials must follow rigid open tender regulations.

Obviously, standardization of designs and equipment would have several benefits. Maintenance personnel answering a trouble call would know what to expect in a crawl space; the now necessary initial search to determine the nature and details of the installation would be eliminated. Management of spares inventory would be simplified, making it much more likely that needed materials would be on hand.

Another advantage of consolidation would be the elimination of current duplication of maintenace arrangements. To illustrate, tenants of HTW serviced dwelling units tend to call NCPC if they find themselves without heat, or with too much of it. NCPC responds to the call, day or night, and checks the NCPC's part of the system -- and, usually, the consumer's part as well. If the problem lies in the consumer's equipment, NCPC advises the tenant of that, and how to get in touch with the building owner's maintenance officer. Few if any of the owners of buildings served by the HTW system have staff members qualified to work on a HTW system, so, typically, HTW maintenance work is tendered annually to local plumbing firms. Therefore, the maintenance officer next calls whichever firm currently holds the contract, and makes the appropriate arrangements. The amount of unnecessary delay, additional administration, duplication of spares inventories and so on is self-evident.

Another point in favour of consolidation is NCPC's steadily expanding policy of scheduled preventative maintenance. Building owners may have standing arrangements for dealing with problems when they arise, but few have arrangements for heading them off.

A less tangible point to consider is the matter of continuity. NCPC personnel know that the Commission's responsibility for the safe and efficient operation of the HTW main system is likely to continue, for some years at least. It seems likely that this continuity is a factor supporting the degree of committment, interest and attention to good workmanship generally evident now in the maintenance of the system. It is not suggested that work done under short term maintenance contracts has in any way been lacking. It would seem, though, that continuing responsibility is the arrangement most likely to assure that high standards will be sustained in the long run.

Conclusions and Recommendations

It is recommended that standards be developed governing the design of consumer service piping, heat exchangers and controls.

It is recommended that only equipment which has been approved by NCPC be permitted to be connected into the high temperature system. The intent is to give NCPC authority to exclude products which, although apparently meeting technical specifications, are by experience known to have short service lives or other undesirable characteristics. The intent is also to permit reasonable standardization, to keep spares inventory and inventory control administration within reasonable bounds.

It is recommended that the policy question of ownership and/or responsibility for maintenance of consumer lines be considered. It is our view that there would be substantial benefit in placing all system

components carrying high temperature water, including consumers' heat exchangers, under NCPC's direct control and responsibility.

CONSUMER CONNECTIONS

Introduction

As indicated, consumers' equipment varies in design, control methods and manufacture. The objectives of this section are

- to describe the common types of consumer interface,
- to review safety implications, and effects on system reliability, and
- to outline recommended minimum standards, and other changes.

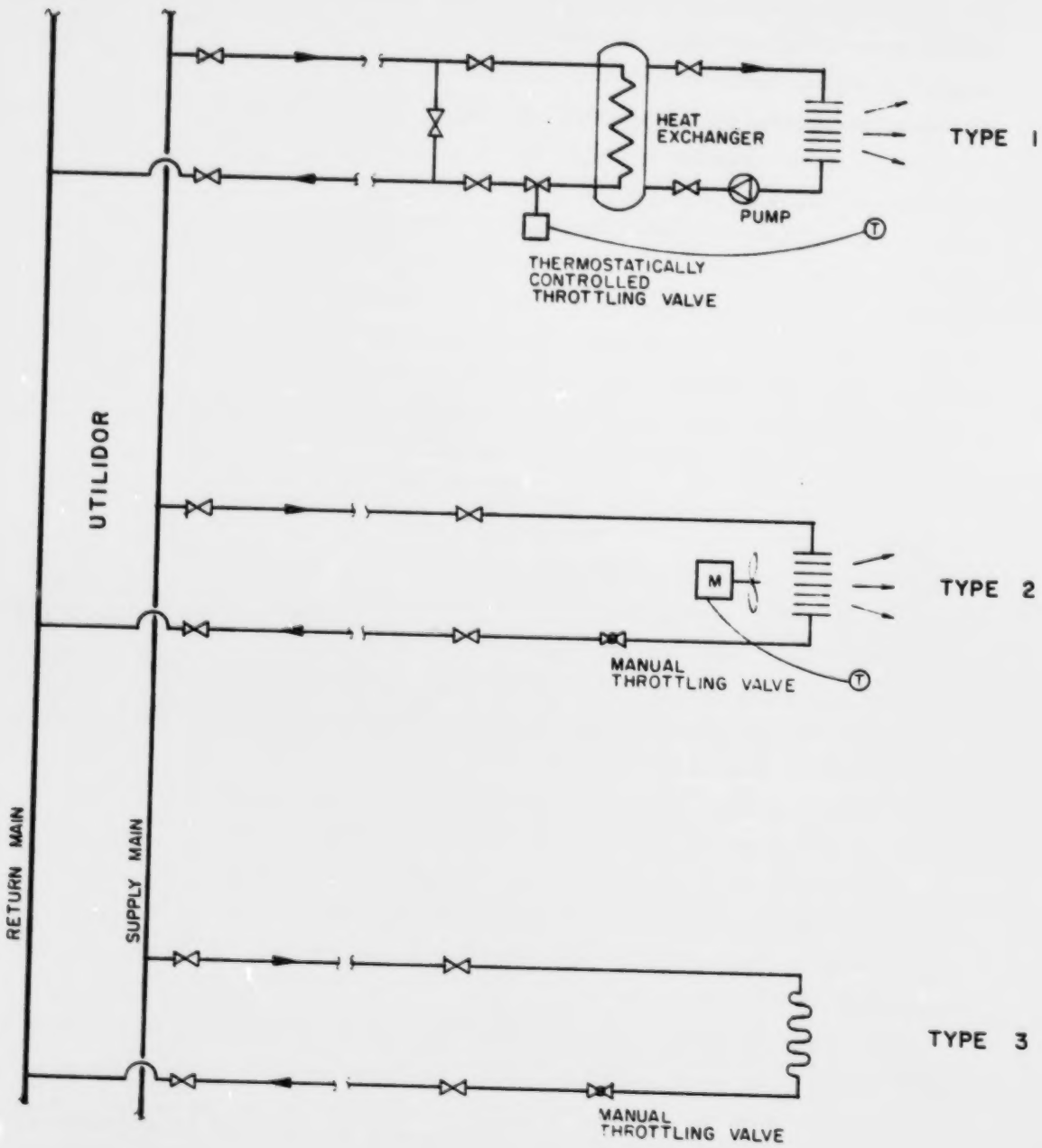
Scope of Investigation

Representative examples of different types of consumer connections were examined in the course of field investigations. NCPC provided a current list of all consumers. Associated Engineering has records of the details of every connection to the system which existed in 1979, compiled from inspections done in that year. NCPC's current list was used to update Associated's records.

Connection Designs

The three different types of consumer connections to the HTW system are shown in Figure 14.

CONSUMER CONNECTION DIAGRAMS



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL.I FIGURE 14

Type 1 is the preferred design, and is by far the most common. Heat from the "primary" (HTW) service line circuit passes to the "secondary" building heating circuit, through the heat exchanger. The building circuit operates near atmospheric pressure, so poses only small risk to building occupants even in quite unlikely failure circumstances. The circulation pump operates at a constant rate, so the amount of heat put into the building is controlled by increasing or decreasing the primary (HTW) flow through the heat exchanger. Primary flow is driven by the pressure differential which exists between supply and return lines. It is controlled by a modulating valve which opens or throttles in response to the building thermostat or, more commonly, an aquastat in the secondary system. The modulating valve is placed in the return side of the heat exchanger, because temperatures are somewhat lower there than on the supply side. In 1984 the HTW system served 226 Type 1 consumers.

In Type 2, there is no separate secondary heating circuit. High temperature water is piped directly through the building heating pipes, and through unit heaters which have thermostatically controlled fans. The primary flow rate may be adjusted manually, at infrequent times, to suit the season. The pumphouse and water plant at Hidden Lake, certain warehouses and the Canadian Forces store are among the approximately half dozen buildings heated in this way.

Type 3 is the simplest design of all. High temperature water is piped directly through heating coils. The rate of hydraulic flow, and therefore heat flow more or less, is controlled by a manually adjusted throttling valve. NCPC's fuel tank heaters are of this type, and several utilidettes are heated in this way.

Discussion

As noted, by far the majority of the consumer connections in existence in 1984 were of the preferred "Type 1" variety. Less desirable designs were

more common in the past, but a number of those have been converted, and some have dropped off the HTW system in favour of individual heating installations.

The Type 2 systems have been in existence, and apparently given completely satisfactory service, for well over two decades. Nevertheless, very unpleasant injuries could result if a heating coil "let go" in, say, the Canadian Forces store during busy shopping hours. Type 2 is, in our view, an unsafe design.

As noted, the only examples of Type 3 connections still in existence are NCPC's fuel tank heaters, and pipes used to heat utilidettes. The fuel tank heaters have been discussed in an earlier part of the report.

In all cases, connections can be isolated from the main system by shutoffs at the main taps.

Experienced Failure Events

The usual problems in service connections are sticking or otherwise failed control valves and, infrequently, perforated heat exchangers.

A perforated heat exchanger allows the higher pressure primary water into the secondary system. The overpressure may open the secondary's safety valve, releasing hot water and steam into the crawl space. The living space overheats, due to conditions below the main floor, and to the unusually hot water now flowing in the secondary heating equipment.

Control valve malfunction stops the heating system from delivering heat when it is needed, or the opposite, from shutting down when it is not needed. It may be caused by failure in the thermostat or control circuit, or, more often, by failure of the drive motor, or by sticking of the valve itself.

Maintenance personnel attempting to isolate a malfunctioning service connection for repairs quite often run into a secondary problem, that of isolating valves stuck in the open position. The cause, build-up of deposits around the valve stem, has been described earlier. Efforts to move stuck valves have on two occasions, at least, resulted in a broken stem and blowout of high temperature water: extremely dangerous to staff. The only method of reducing the liklihood of this sort of occurrence is routine servicing of valves, on a scheduled basis.

Conclusions and Recommendations

Malfunctions in consumer connections pose little danger to the HTW main system. On the whole, failures involving even small losses of high temperature water (through heat exchanger perforations or valve blow-outs) are quite infrequent. Most connections can be shut off at either the heat exchanger or the main taps, and if all this fails, then at worst a short section of HTW main can be isolated while more extensive repairs are made.

The principal dangers, where they exist, are to maintenance personnel. The principal causes are lack of preventative maintenance on valves, crawl spaces which are not laid out with escape in mind, and, possibly, the practice of allowing secondary safety valves to blow into crawl spaces rather than below the building.

Recommendations for the conversion of the Type 3 (fuel tank) connections have been made, earlier in the report. It is also recommended that the Type 2 connections be converted to Type 1, with high priority given to the Canadian Forces store and any other buildings readily accessible to the public or used as residences. It is also suggested that NCPC give consideration to converting the heating systems in the two buildings at Hidden Lake. At the same time, it is appreciated that the buildings are

not occupied, only visited, and then only by NCPC staff familiar with the HTW system: direct use of HTW in the building heating system might be judged acceptable under these circumstances.

The recommendation that responsibility for maintenance of consumer facilities carrying high temperature water be transferred to NCPC is reiterated. Naturally, the cost of service rate structure would have to reflect the transfer of maintenance responsibility and cost from the owner to NCPC.

PART IV
POTENTIAL CHANGES

Heat generation, the distribution system and consumer connections were discussed in the first three parts of this report. Particular attention was paid to factors which might impair the heat distribution system's reliability, or might threaten the safety of persons or property.

Part IV deals with changes which might be made to improve reliability and safety. Some, such as improving the arrangements for heating heavy fuel in storage tanks, have been mentioned before. As will be clear from earlier discussions the system is, on the whole, strongly built and well maintained, and its service record indicates a good standard of reliability. The system's principal apparent weakness is economic. That is a matter for discussion in the Phase II report, but it has implications for some of the suggestions made here.

POTENTIAL CHANGES IN HEAT GENERATION FACILITIES

Changes in the heat generation plant which might be considered include

- changing the fuel tank heating fluid, from high temperature water to glycol at atmospheric pressure, and
- moving boilers, so that the large Volcano unit is in one plant, and the two Cleaver Brooks ones are in the other.

Change Fuel Tank Heating from HTW to Glycol

The objective of this change would be to prevent a recurrence of the 1974 incident, in which leaking heat tubes in a fuel tank led to the contamination of a substantial amount of stored heavy fuel.

The proposed change is outlined in Figure 15. High temperature water to glycol heat exchangers, glycol circulation pumps and glycol expansion tanks would be installed in the power houses. Glycol supply and return lines, insulated and metal-jacketed, would run to the tank farm, and branch as needed to serve different tanks. Isolation valves would be installed at branch points. Expansion tanks would be operated at atmospheric pressure, or as close to atmospheric as elevation differences permit.

The capital cost of the change is estimated to be $160,000. Operating costs over and above present operating costs would be negligibly small, in fact, better control of heat could reduce operating costs.

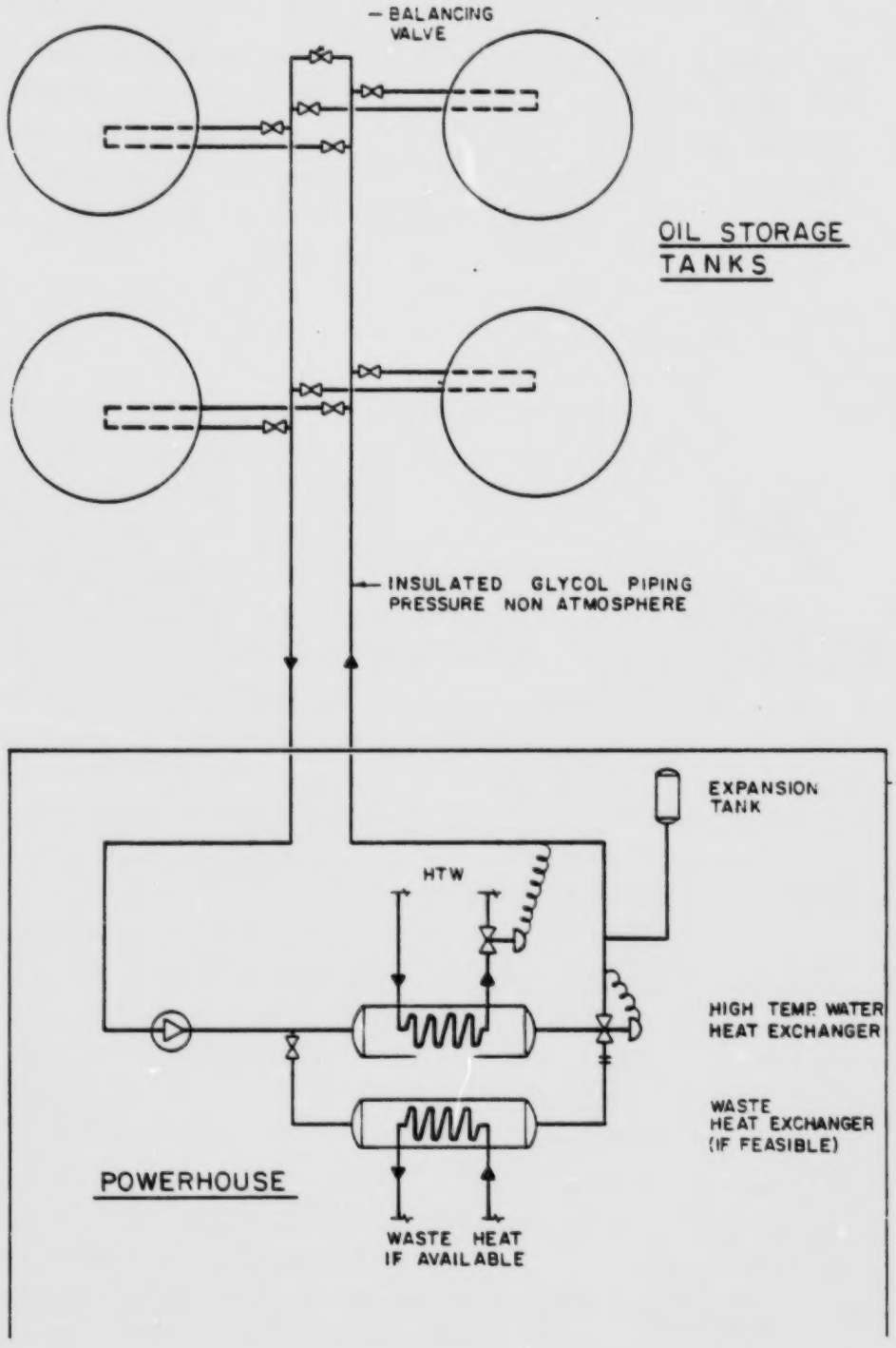
The costs which might result from failure of a fuel tank heating coil are quite high. The typical volume of fuel which might be affected is about 1,000,000 Ig, worth, at 1984 prices, $1.5 million. Repairs, cleaning and similar expenses would be additional, and so would any extraordinary measures needed to keep the plant from running short of fuel before the usual summer re-supply. Finally, low pressure in the HTW system would allow fuel to be drawn into it, which could cause a shutdown of the system, with disasterous consequences if that occurred in winter.

The probability of a second fuel contamination incident occurring some time in the future is high. The potential consequences are so severe that the proposed change is strongly recommended.

Move Boilers

The objective of moving one or more boilers would be to divide total capacity about equally between the two powerhouses. Either powerhouse would then be in a position to carry the full heating load in the event of some total disaster in the other. Currently, the K Plant has the Volcano

HEAVY FUEL STORAGE GLYCOL HEATING SYSTEM



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE N.T.S

VOL. I FIGURE 15

and small Cleaver Brooks boilers, giving it a total capacity of 120 million BTU/hr, and the EMD plant has the large Cleaver Brooks, 63 million BTU/hr.

The reasons behind the existing, moderately unbalanced arrangements are historical. The "old" plant, now gone, contained steam boilers, installed to run steam turbine electrical generators, and to heat the HTW system as well. The Volcano was one of the major pieces of new equipment installed in the K plant, when it was built in 1971. The small Cleaver Brooks boiler was added in 1977. The logical place for it at that time was the K plant, where it remains.

The EMD plant does not have space for an additional boiler, but balance could be achieved if the Volcano and the larger Cleaver Brooks exchanged places.

The capital cost of such a rearrangement might be in the range of $100,000*.

The benefit to be gained is full standby in the event of complete loss of one of the powerhouses. Something to be considered in evaluating that benefit, is the likelihood of a second major disaster. The likelihood of another fire is thought to be fairly low, in view of the better standard of fire prevention in materials and design. Another point to consider is that maximum demand is about 69 million BTU/hr, so the large Cleaver Brooks boiler can manage full demand down to about -45°F (-43°C) with current loading. It is likely that ways would be found to "get by", if it became necessary to do so, in extreme weather.

*Internal cost studies done by NCPC personnel; private communication.

It is considered that the benefit of the rearrangement would not justify its cost.

POTENTIAL CHANGES IN HEAT DISTRIBUTION FACILITIES

Changes in the distribution system which might be considered include

- replacing expansion joints, as the need for replacement arises, with units selected to traverse at least down to freezing,

- replacing expansion joints, as the need for replacement arises, with ones of different design which are not prone to fatigue, and

- looping the system around Samuel Hearne Secondary School.

Replace Expansion Joints

Although the incidence of failure in expansion joints has been low, a review of other available designs has been made to see if a better one has been developed. A disadvantage of designs other than the flexing bellows type, insofar as use in the Inuvik utilidor is concerned, is that they are intolerant of bending, and require a high degree of accuracy in pipe alignment. It would appear to be difficult to meet required tolerances in initial installation in a utilidor, and, if that were accomplished successfully, misalignment might develop at a later date due to heaving of piles. The existing Flexonics "high corr" bellows units are forgiving of minor misalignment, and in all respects appear to be the best of available choices. No change in design is recommended.

It is recommended that, as joints come up for replacement, the replacement units be chosen for a traverse length equivalent to a temperature range from freezing to 350°F. If security in the event of some winter emergency is desired, then the design minimum temperature might be reduced further, even as low as the extreme minimum ambient of -60°F.* However, shutdown and cooling to these temperatures would have such severe implications for the water system and consumers that it is far more important to make every effort to avoid such an occurence, as opposed to preparing the HTW system to survive it.

System Loop Around Samuel Hearne Secondary School

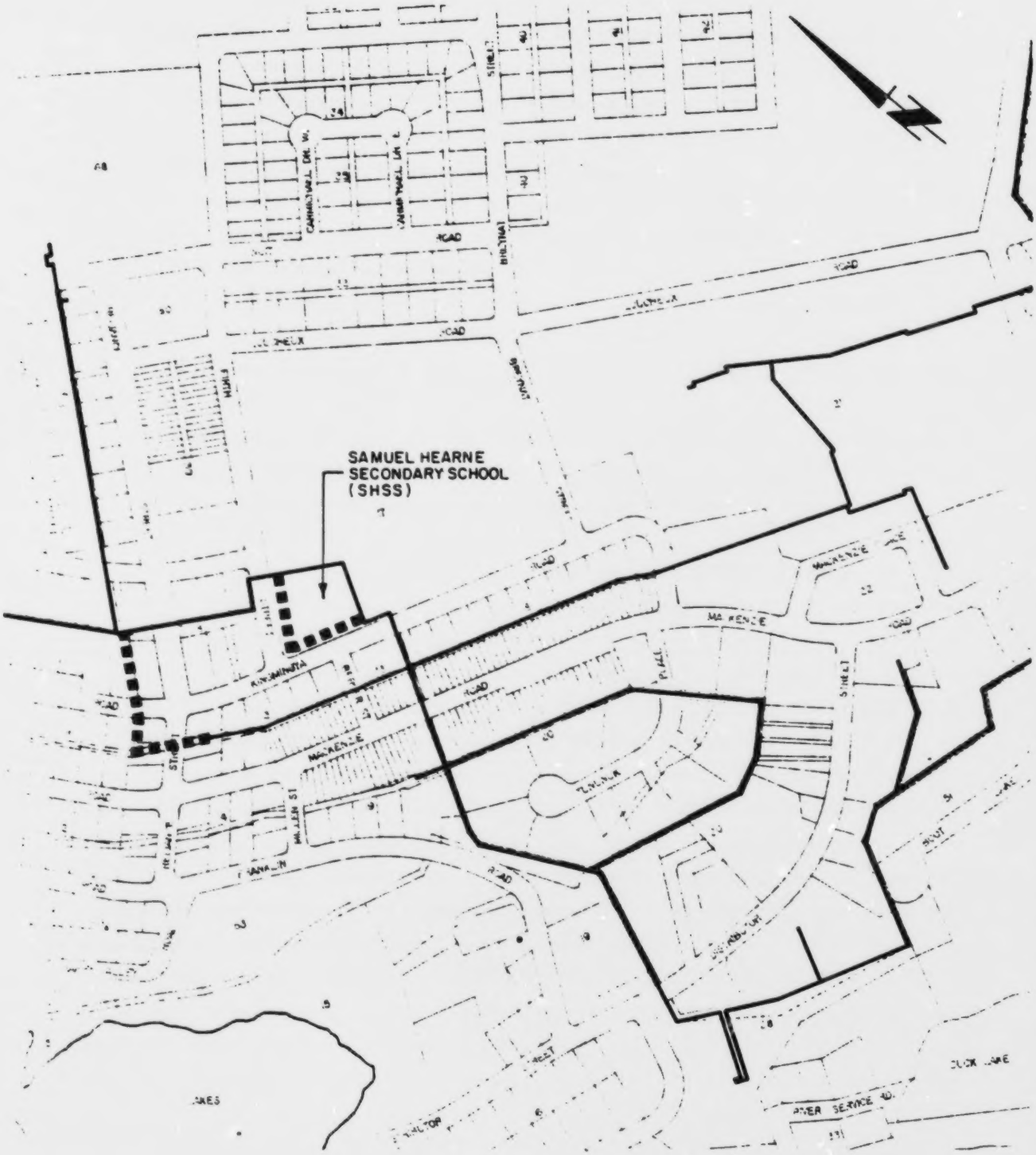
The purpose of the loop would be to assure continuity of service in Blocks 36 and 68 (arena), and the Federal housing complex (Blocks 45, 46 and 47), in the event of the utilidor being cut by a major fire in Samuel Hearne School.

One route would run from Block 13 (CNT), west across Reliance Street, 30 m into Block 11, and then east to Junction 114. In addition to the new road crossing at Kingminga, routing through the public apartments at the west end of Block 21 might be difficult and relatively expensive. The route, some 190 m long, potentially could bring service to, at most, five new single family residences. This route, and the one described below, are shown in Figure 16.

The simplest route is to follow the edge of the school ground, more or less along the south and west boundaries of Block 17. The length is 160 m

*As noted earlier, special alloys are required for temperatures below -20°F.

POSSIBLE HTW ROUTES AROUND SHSS



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE 1 : 100

VOL. I FIGURE 16

and the cost, using jacketed pipes rather than utilidor, would be about $240,000*. There would be no road crossing. No new customers would be served.

Another strategy altogether would be to establish standby heating facilities somewhere on the north branch of the utilidor, so it could operate on its own if isolated. However, the cost would be in the neighbourhood of $1.2 to $1.5 million,** far greater than the equivalent cost of the standby loop, and this option is discarded.

Evaluation of the benefit of this change involves making an estimate of the likelihood of it being needed, at some time.

The number of fires in the NWT averages five per 1000 population per year (Heinke and Bowering, 1983). This is equivalent to 100 per 1000 population over a 20 year planning period, or 400 to 500 fires in Inuvik over the next 20 years if the population averages 4000 to 5000.

The Town has something in the neighborhood of 1000 buildings. If all buildings including schools have the same susceptibility to fires (admittedly they don't), then there is about a 50 percent chance of Hearne School having to survive a fire some time in the next twenty years.

*Based on experienced cost per unit length of utilidor construction in Inuvik in years past.

**The cost was estimated to be $803,000 in Edmonton, using published data. Equivalent costs for mechanical installations in Inuvik are at least 40 percent greater.

Many fires are detected and put out at an early stage. Samuel Hearne School is sprinklered and under generally good surveillance, and Inuvik has a responsive and well organized fire brigade. The probability that a fire might be serious enough to, say, level one wing of the building, and the utilidor with it, might be 20 percent. If winter is taken to be half the year, then the cumulative risk factor of a wintertime disaster is about 5 percent.

If the utilidor were destroyed in winter (50 percent of the year), then we do not see any way of maintaining service, or of restoring it quickly, to north branch consumers. About 110 housing units would be untenable, and a large amount of damage would be done to plumbing. The water system in the north area is also dependent on HTW heat, but probably would be kept running by resourcefulness of NCPC staff, if they were not too committed elsewhere.

The total cost, including temporary accommodation of evacuated residents, is highly speculative. It could be as much as $3 or $4 million, exclusive of much severe inconvenience. With a probability of a wintertime occurrence of 5 percent, the "risk cost", which is even more speculative, becomes $150,000 or $200,000. This is in the same general range as the cost of the suggested prevention measures, so economics alone do not lead to a clear choice. When other factors are considered as well, such as inconvenience, and disruption of employment and productivity, the better choice would appear to be to construct the backup loop.

POTENTIAL CHANGES IN CONSUMER CONNECTIONS

Proposed changes in the means of heating stored fuel have been described earlier. The additional change recommended is the conversion of some Type 2 connections to Type 1, principally for safety.

The Type 2 connections which clearly warrant conversion are those in which a heating coil failure could expose building occupants to injury. Other installations, where high temperature water only enters a mechanical room and is used to heat air, quite possibly would be considered to be safe. It is recommended that all Type 2 installations be inspected by a qualified person from Department of Public Services, and decisions made as to which installations should be altered.

Change Type 2 Connections to Type 1

The change would involve installing a heat exchanger in the crawl space or a building mechanical space, near the point where the high temperature lines enter the building, and operating a normal Type 1 secondary heating system from that. Secondary temperature would be much lower, so all heating equipment would almost certainly have to be replaced, and larger diameter pipes might be needed as well. Simply stated it will probably be necessary to install a complete new heating system. Being faced with a complete change, building owners would probably wish to look at all suitable options for heating, including private oil-fired boiler and oil-fired warm air systems.

The most probable range of cost for each building is $15,000 to $30,000.

MISCELLANEOUS RECOMMENDATIONS

The purposes of this phase of the study are to determine if the HTW system is significantly lacking in safety or reliability, due to design or to aging, and if so, what should be done about it. Perceived problems, and potential problems, have been described. A number of lesser issues have also come to light in the course of the work, and those are summarized below.

Operator Safety

This is a "lesser issue" only in the sense that a number of improvements could be made without large expense, of either capital or operations funds. Clearly, every reasonable effort ought to be made to reduce the danger involved in working around high temperature water, recognizing that danger cannot by any practical means be eliminated altogether.

All vaults are raised above the ground, some a couple of metres or more. The doors invariably open outward, so getting in, from a ladder propped against the side of the structure and supported on uneven ground, is difficult and accident prone. It is recommended that landing and access ladders, or access stairs, be added to vaults not already having them. It is thought that the cost of doing this would be in the neighbourhood of $7000.

The danger of high temperature water in crawl spaces has been mentioned repeatedly. It would be reduced, though not eliminated, if the service connection was always shut off at the main taps before the crawl space was entered. It is recommended that this be a mandatory first step in any case where work is to be done on HTW equipment in a crawl space, or where a fault is suspected. The shutoff valves within the crawl space, at the heat exchanger, should not be relied on.

It is also suggested that consideration be given to installing blow-offs on service lines, at the utilidor, for depressurizing and cooling the service (at least to boiling) after it is isolated and before work inside the crawl space begins. A blowoff could be a tee, valve and a pipe stub within the utilidor, to which a standard blowoff discharge pipe (part of the tool kit) would be attached. The time to install belowoffs would be during any routine shutdown of the HTW system for other maintenance.

Standardization

Standardization is a worthwhile objective, especially with respect to the design of service connections and the selection of equipment. It reduces the problems of spares inventory and administration. It also greatly simplifies maintenance and repair work, which is often done under difficult conditions where any simplification would be much appreciated.

Scheduled Maintenance

The HTW system represents an extremely costly investment, and the benefits of preserving that through well planned routine maintenance procedures need no elaboration. As discussed earlier, it is recommeded that these benefits be extended to consumer connections, as well as the main system.

Base Plans

The HTW system base plans produced in the course of this study are incomplete: a few expansion joints, valves and other features have been ommitted, in most cases due to the carrying forward of ommissions from other sets of plans. It is expected that NCPC will find the base plans useful in managing maintenance, and similar activities. If so, it is recommended that the Commission continue to update them when errors or ommissions are found.

Listed Maintenance and Repairs

Items of needed maintenance were noted in various sections of the report. NCPC personnel participated in field work, and the Commission is aware of all of these items. For convenience, all are listed below. It is important to bear in mind that the list is based on sampling inspections, not a comprehensive survey of the entire utilidor. Furthermore, NCPC's maintenance staff will have dealt with many items before this report is distributed.

Items noted that require maintenance of a routine nature are:

1. Leaking valves, J64, J68, J72, J119, Int A, Int B, Int D.

2. Rollers and/or guides requiring realignment or tightening, J72 (north branch), Int A, Int B (toward C), Int D.

Items noted that require maintenance of a non-routine nature are:

1. Disintegrating concrete pile caps or anchor blocks,

   - Block 20 by Mackenzie Hotel,
   - Bend 114C, Block 36, 480 ft NE J114,
   - Bend 114D, Block 36, 240 ft NE J114,
   - Bend 115C, Block 36, 240 ft SE J115.

All require replacement.

2. Rusting steel building frames, J115 and J119, require power brushing and repainting to protect structural integrity in the long term.

3. Circulation pump frame requires replacement, J116.

4. Vault and utilidor cladding damaged and requires repair, J114 and J116.

5. Utilidor piles deteriorated, requiring repair, Block 21, by Catholic Church.

6. Utilidor piles heaved causing tilted utilidor, and some piles deteriorated, requiring re-levelling and repair, Blocks 25, 26, 30 and surroundings.

7. Leaking expansion joints; locations shown in Figure 10.

Corrosion Coupons

It is recommended that NCPC resume the practice of installing and monitoring corrosion test coupons in the HTW lines in the powerhouse.

Pressure Sensors

The monitors at the powerhouse are adequate for nearly all purposes. However, pressure sensors at the top ends of the HTW system would give much earlier warning of a severe leak, should one occur. Sensors could be tied into the plant computer control system, being installed. It is suggested that they be given consideration.

REFERENCES

Associated Engineering Services Ltd., Inuvik High Temperature Water Distribution System Analysis, report to Northern Canada Power Commission, 1978.

Associated Kellogg Ltd., (R.J. Kronstedt, P.Eng.), letter report to Associated Engineering Services Ltd. on Pipe Coupons, Inuvik HTHW System, October 5, 1984.

Hanson Materials Engineering (Western) Ltd., Ultrasonic Wall Thickness Measurements on Nine Pipe Coupons From The Inuvik HTHW System, report to Associated Engineering Services Ltd., 1984.

APPENDIX I

UNITS, ABBREVIATIONS AND CONVERSION FACTORS

TABLE I.1

UNITS AND ABBREVIATIONS

Distance

mm	= millimetre		
cm	= centimetre	in	= inch
m	= metre	ft	= foot
km	= kilometre	mi	= mile

Velocity

m/s	= metre/second	ft/sec	= feet/second

Volume

m^3	= cubic metres	Ig	= imperial gallons
		Mig	= million imperial gallons

Flow

L/s	= litres/second	Igm	= imperial gallons/minute
m^3/s	= cubic metres/second		

Concentration

mg/L	= milligrams/litre	ppm	= parts per million

Force

N	= neuton (kg m/sec^2)	lb	= pound (force)

Pressure

Pa	= Pascal (N/m^2)	psi	= pound/square inch

Energy

J	= Joule	BTU	= British Thermal Unit

Power (Energy/time)

W	= Watt (J/s)	BTUH	= BTU/hr
		hp	= horsepower

Multiples

G	= giga (10^9)	MM	= million (10^6)
M	= mega (10^6)	M	= thousand (10^3)
k	= kilo (10^3)		
m	= milli (10^{-3})		

TABLE I.2

USEFUL CONVERSION FACTORS

Metric to British		British to Metric	
1 cm	= 0.394 in	1 inch	= 2.540 cm
1 m	= 3.281 ft	1 foot	= 0.305 m
1 m	= 1.094 yd	1 yard	= 0.914 m
1 km	= 0.621 mile	1 mile	= 1.609 km
1 m^3	= 35.31 ft^3	1 ft^3	= 28.32 L
1 L	= 0.220 gallon (Imp)	1 gallon	= 4.546 L
1 kPa	= 0.145 psi	1 psi	= 6.89 kPa
1 kJ	= 0.95 BTU	1 BTU	= 1.05 kJ
1 kW	= 1.34 hp	1 hp	= 746 W

APPENDIX II

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VOLUME II

SYSTEM CAPACITY, EFFICIENCY AND HEAT RECOVERY POTENTIAL

INTRODUCTION AND SUMMARY

Inuvik was founded in the mid-1950's, born of the Federal Government's need for a regional service and adminsitrative centre near the mouth of the Mackenzie River.

It was decided that new community's planners and engineers should use, and test, the most advanced cold regions concepts and technology then available. Inuvik's ice-rich, thaw-sensitive permafrost soils dictated that water and sewer piping be above ground, which led to the planning of Inuvik's now widely known utilidor system. At the same time, it was decided to provide heat to most or all buildings from a central plant, using a high temperature water (HTW) heat distribution system.

It is likley that the decision to build central heating was influenced by both the utilidor system's need for heat to prevent freezing, and the expected efficiency of a central plant. More importantly, however, it was intended that electrical generators would be driven by steam turbines, and that the HTW system's heat would be taken from the turbines' exhaust, an arrangement which would achieve a high degree of fuel efficiency throughout the winter. As it happens, NCPC* has moved away from co-generation of electricity and heat, owing primarily to the inefficiency of this system in summer. All electricity is now generated by diesel units. An attempt in the early 1970's to recover heat from the engine stacks was abandoned due to probelms with corrosion. The new plant recently commissioned has provision for capture and use of some heat from waterjackets. Heat for the HTW system is now provided by large hot water boilers, installed solely for that purpose.

*Northern Canada Power Commission

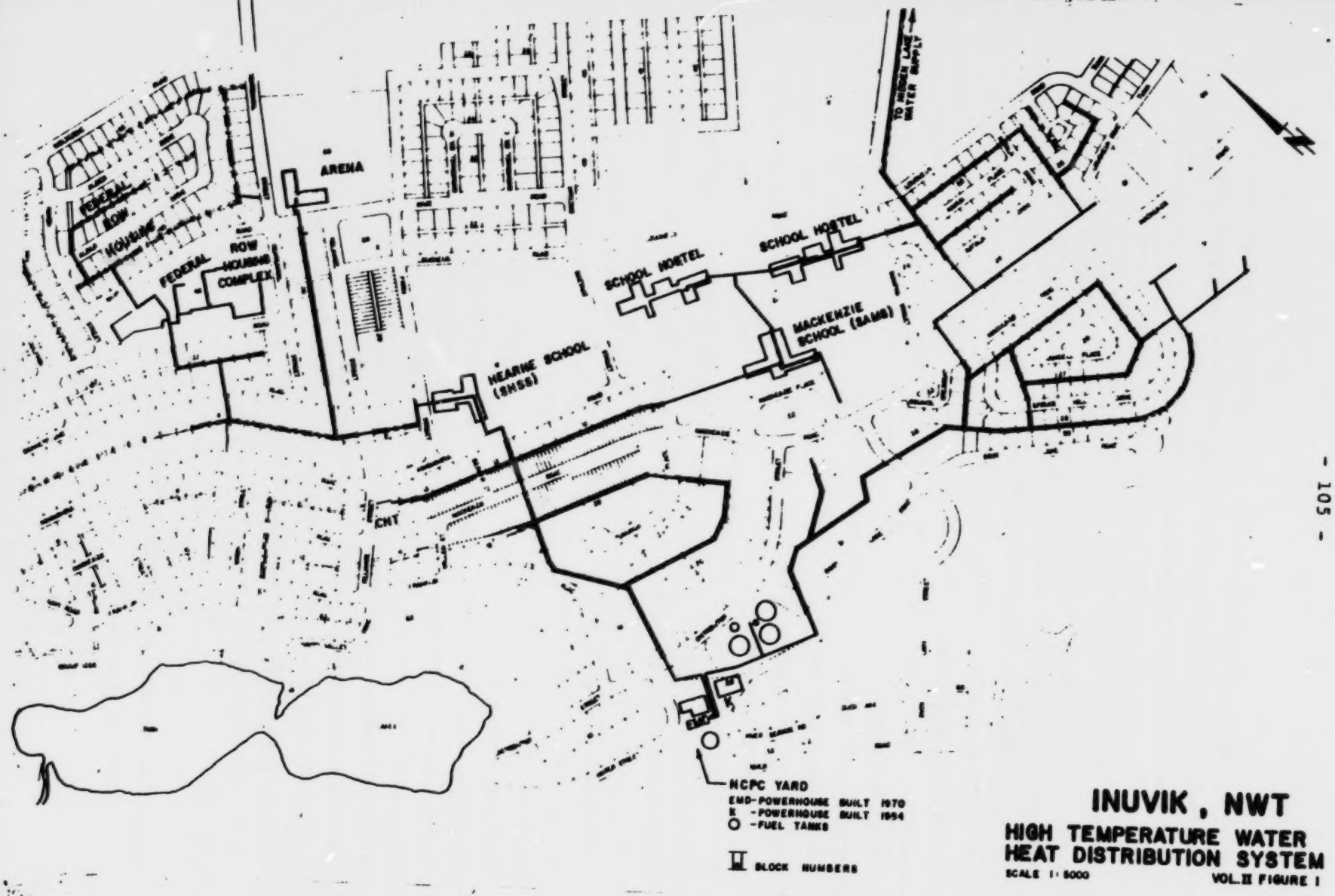
High temperature water heat distribution mains were installed, along with water and sewer mains, in all of Inuvik's utilidors built between 1958 and 1971, including the run from the school residence blocks to Hidden Lake. As can be seen in Figure 1, the HTW system was also extended north to the CNT building, across Inuit Road to the arena, and to the apartment building at the south end of Block 37. At the same time, it was not built into Co-op Hill*, the west end residential areas, or any main runs of utilidors built after 1971.

The HTW system is found in some 5.3 miles (8.6 km) of utilidor, just over half of Inuvik's total of 10 miles (16 km).** It now provides heat to 243 buildings, and to other users, of which fuel storage tanks and the domestic water system are examples, through 14 additional connections. Supply and return pipes are welded steel, in sizes up to 8 inch, and the flow rate at the powerhouse is 1200 to 1300 Igm. The peak heating load is in the neighbourhood of 70 million BTU/hr (70 MMBH). Consumption of heavy fuel ranges from 2600 Igd in summer to 9200 Igd during cold winter weather, and totals 2.2 million gallons per year. Output and return temperatures are 350°F and 250 to 280°F respectively, and system pressures are 200 to 250 psi.

A primary reason for the decision not to include HTW piping in utilidors built during the last decade or so is the very high capital cost of welded steel piping, larger utilidor box, restraints and expansion features, and building connections. In recent years, however, a more compelling reason has been the perception that HTW heat is costly, relative to alternatives.

*Blocks 32, 34, 35 and 40.

**The HTW system was built of components made to Imperial measurement standards and most data and records are in imperial units. The Study Management Committee elected to use imperial units in this study as well. SI units appear occasionally, for instance, in quotations.



INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE 1:5000

VOL. II FIGURE 1

A number of non-government consumers have installed their own building heating facilities, and gone off the HTW system. In discussions, two have reported capital cost payback periods of under two years.

For obvious reasons, the economics of the HTW system have become a source of concern. Questions have also been asked about the system's condition, reliability, and safety, in view of its age. In May, 1984, the Department of Public Works, Government of the Northwest Territories retained Associated Engineering to investigate and report on these two issues. The work was done under the guidance of a Study Management Committee, whose membership includes representatives of the Department of Public Works and Highways and Department of Local Government, Government of the Northwest Territories; Department of Energy Mines and Resources, Canada; NCPC, Town of Inuvik, and the Consultants.* Volume I of this report deals with the condition of the system, and matters affecting safety and reliability. This Volume, Volume II, deals with the system's operational characteristics and options for improving its economics; in particular, the potential for recovery and distribution of heat rejected and lost from diesel generators.

As reported in Volume I, the district heating system is strongly built, well maintained and quite reliable. NCPC's heat generation facilities appear to be sound, reliable, in good condition and well supervised. The HTW distribution system shows little sign of aging, although insulation has been lost in some places, especially vaults. The majority of consumer connections are properly designed, although many receive insufficient preventative maintenance. The Volume I report listed a number of maintenance needs, and made other recommendations pertaining the continued safety and reliability.

*Committee Members and others who participated in Committee proceedings are listed in Appendix.

Volume II covers two topic areas. Parts I, II and III deal with the system as it exists, its capacity and efficiency, and with improvements that might be made in the distribution system, consumer equipment and consumer buildings. The prospect of abandoning district heating altogether in favour of individual building heating systems is also addressed. Parts IV and V deal with waste heat recovery and other fundamental changes in design and operations concepts, and with the effects of such changes on the distribution system and on consumers.

Analysis has shown that the district heating system performs well at current loads. Its capacity is limited by the hydraulics of the distribution network, and not by the capacity of the boiler or the circulation pump. The distribution system's capacity exceeds current load by ten to twenty percent. If the distribution system were rebuilt to improve its hydraulic capacity, a point would obviously be reached where larger boilers would also be needed.

The addition of any significant load anywhere on the system affects hydraulics throughout. Estimating the probable effects, and in particular the effects in the more vulnerable areas of the system, necessarily involves modelling the complete system with the proposed change incorporated.

The extremities of the system are the most vulnerable to heat shortage due to hydraulic overload. The north end of the system tends to be affected first, and most, regardless of where the load is placed in the system.

Of the 443,800 MMBTU* input into the system annually as fuel, 323,000 MMBTU, 72.8 percent, reaches consumers in the community or in the powerhouse area. Losses in the powerhouses amount to 84,500 MMBTU, 19 percent of input fuel. Losses in the distribution systems are 36,300 MMBTU, 8.2 percent of input fuel, and 10.5 percent of the heat sent into the distribution system.

*Million BTU

Utilidor heat losses could be reduced by 12 to 14 percent by insulating piping in vaults, and this measure is recommend.

Scheduling of boiler output temperature as a function of outdoor temperature potentially could reduce utilidor heat losses by a further 10 percent. The cost of the work would not be large, and the annual saving is estimated to be $39,700. It is not known to what extent scheduling might affect the reheating rate of domestic hot water heaters and, of more consequence, the service lives of expansion joints and boilers. Scheduling is recommended, on a trial basis. If it is adopted, the output temperature scheduling range should be kept small, initially. It would be expanded toward the full suggested 100°F (350°F to 250°F) gradually over a period of months, and effects monitored.

The potential effect on the HTW system of retrofitting customer buildings for heat conservation has been assessed. It is considered that costly and extensive building energy conservation retrofit projects are unlikely to be cost effective. However, sealing and weatherstripping of buildings in need of that kind of attention is certain to be cost effective, and may have a payback period of as little as a single winter. Adding insulation in accessible ceiling spaces is also likely to be cost effective.

Cost effective retrofit measures, even if widely applied, would be unlikely to reduce total system heat load by more than 10 percent. A load reduction of this magnitude would have little or no effect on the operation of the HTW system. The unit cost of energy production would probably increase by about 2.5 percent, since fixed costs would be distributed over a smaller revenue base. The average consumer would realize a net saving of 7.5 percent. A cost increase might be avoided if the lost load could be replaced with little capital outlay, for example, by encouraging consumers who have disconnected to resume use of HTW heat, or by gaining new customers among buildings already located beside HTW utilidors.

A question of some importance is whether it is more cost effective for a consumer to stay on the HTW system or install self-contained heating. A similar choice applies to any new buildings built adjacent to HTW utilidor.

Analysis shows that the cost of HTW heat and the cost of the fuel needed to generate an equivalent amount of heat using self-contained facilities are about the same. However, the capital cost of an independent heating system, and the maintenance costs as well, exceed equivalent costs for an HTW connection.

Therefore, existing consumers will benefit by remaining on the system. Similarly, it would in most cases be more economical to heat a new building being built adjacent to existing HTW utilidor by HTW heat, than independently. Finally, in some cases it might be cost-effective to convert existing buildings located adjacent to HTW utilidor from independent heating to HTW.

It is our impression that many residents of Inuvik believe that it is less costly to generate heat independently than it is to buy it from the HTW system. A widespread opinion of this sort could adversely affect the viability of the HTW system in future. Unit costs necessarily would rise if system loading were to decrease through departure of existing customers. It is suggested that NCPC may find it desirable to counteract misconceptions about heating economics, if they exist, through planned publicity.

Since the HTW system appears to be cost effective, at current fuel and energy price relationships, it is recommended that it remain and not be abandoned. At the same time, it must be noted that comparisons between district heating and alternatives are based on the current non-government

price for HTW heat, and current prices for P40 and P50 heating oil. Conclusions are extremely sensitive to any future change in relative price levels.

Although the district heating system as it stands, with the past capital cost of utilidors presumably by now dispensed with in some fashion, is competetive with alternatives, it is unlikely to be cost effective to extend it except to some very high density development. The high cost of building HTW distribution mains opposes the central heating system's cost advantages due to fuel efficiency, lower cost fuel and centralized maintenance of facilities.

The economics of extending the HTW system into some new area would have to be evaluated carefully, on the basis of the specific details of the proposal being considered. The evaluation would have to include an analysis of potential effects on existing consumers, and on the heat generation plant.

The possibility of metering heat has been investigated. The capital cost of meters is likely to be in the neighborhood of $0.6 to $1.9 million, $2200 to $7500 per unit.

Metering would be well received by consumers, and could be a factor in encouraging consumers to stay on the HTW system. It would also encourage heat conservation.

The cost efficiencies of the heavy and light fuels now used by NCPC have been compared. Heavy fuel is, at the current relationship between prices, substantially more economical than P40 for generation of heat. The same would be true for generation of electricity if engine maintenance costs are independant of fuel choice, and it is understood that NCPC is investigating this question.

The studies done in the past on the natural gas resources around Inuvik indicate that the benefits of a natural gas supply would be greatest if the supply was tapped from a transmission main to the South, as compared to building a small gas plant and transmission main solely to serve Inuvik. Opinions appear to be divided on the question of whether an independent supply serving Inuvik alone would be viable.

Recovery of waste heat and distribution of recovered heat through a low temperature glycol distribution system, similar in form and operation to the HTW system, probably would be cost effective. However, the payback period is long; 12.5 years at a discount rate of 8 percent. Economic conclusions are quite sensitive to future variation in relative levels of capital and operations costs, fuel costs and discount rate, as well as to uncertainties in cost estimates. On the whole, this concept is not considered to be very attractice.

It would also be possible to recover waste heat from engine stacks and transfer it directly to the HTW system. Unfortunately, the payback period for this scheme is nearly identical to the one just described, and it is not considered to be attractive either.

About half of the heat now discarded to atmosphere through engine cooling systems could be used to heat fuel tanks and municipal water, at the water treatment plant, all within NCPC's yard. The payback period for this option is believed to be less than eight years, and it is recommended that NCPC give it additional consideration.

PART I

DESCRIPTION OF EXISTING DISTRICT HEATING SYSTEM

INTRODUCTION

Parts I, II and III deal with the existing heat supply and heat distribution system, and with improvements that might be made in the distribution system, consumer equipment and consumer buildings. The prospect of abandoning district heating altogether in favour of individual building heating systems is also addressed. Parts IV and V deal with waste heat recovery and other fundamental changes in design and operations concepts, and with the effects of such changes on the distribution system and on consumers.

Part I provides descriptions of the HTW system, the consumers it serves and its operation. The methods used in analysing the existing system are described in Part II. Part III presents the results of analyses, and recommendations.

Some of the system description which follows has been condensed from the first volume of the study report. It is included so that Volume II can stand alone.

SYSTEM COMPONENTS

Introduction

The three principal components of the HTW system are

- the boilers in NCPC's powerhouses which generate heat,

- the high temperature water mains in the utilidor system which distribute it, and

- consumer connections, which take heat from the system through small diameter piping and heat exchangers.

Heat Generation System

Currently, all heat distributed by the HTW system is generated by three oil-fired boilers, located in NCPC's two powerhouses.* The layout of NCPC's plant and fuel storage yard is shown in Figure 2.

The three boilers have forced draft modulating burners and all other usual devices which enhance efficiency, but none have equipment for flue gas heat recovery. All are understood to be in very good condition. Capacities are listed in Table I.

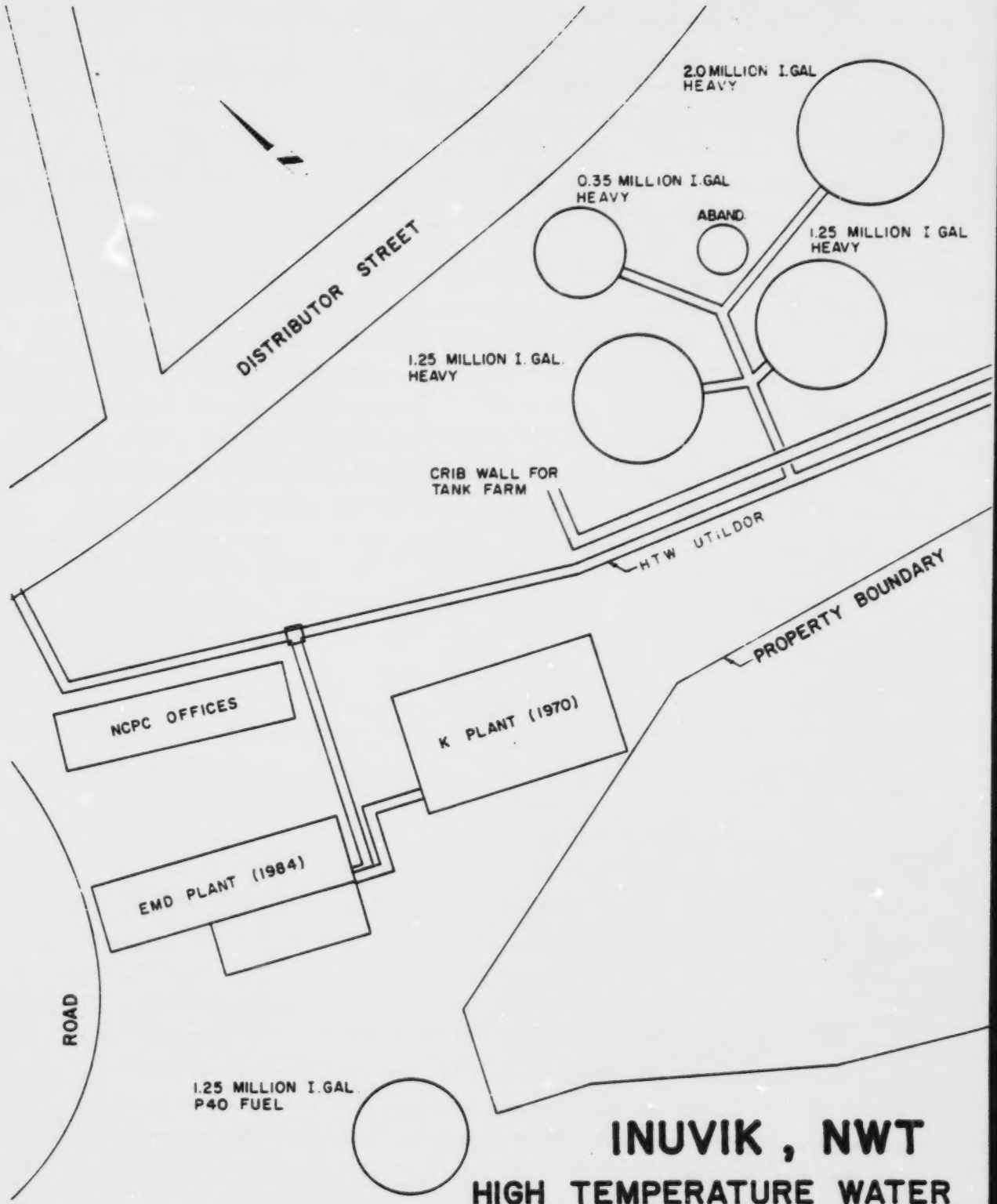
TABLE 1

INSTALLED BOILERS

Unit	Make	Capacity MMBH	Built	Location
CB D60	Cleaver Brooks	30	1976	K
CB DL94	Cleaver Brooks	63	1983	EMD
Volcano	Volcano	90	1971	K

*The "old" powerhouse was built about 1958, and was destroyed by fire in 1983. The "K" plant was built in the early 1970's, and is now sometimes called the "old" plant. The "EMD" plant was built in 1984, to replace the one lost by fire.

HEATING PLANTS AND OIL STORAGE TANKS



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HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE 1:100

VOL. II FIGURE 2

NCPC fires all boilers with a heavy fuel, "No. 5" or "Bunker C", which is produced in Norman Wells. Current consumption by the HTW system boilers is about 2.25 million Ig (Imperial gallons) annually, plus or minus 10 to 15 percent according to the severity of the winter. The fuel is heated, in storage and in supply lines, as necessary to maintain flow.

Other HTW system equipment located in the powerhouses includes the distribution system circulation pumps, and expansion and overflow tanks. Simplified schematic diagrams appear in Figure 3. As shown, the supply and return distribution pipes are connected directly to the boiler water tubes, and circulation pumps are placed in the return main.

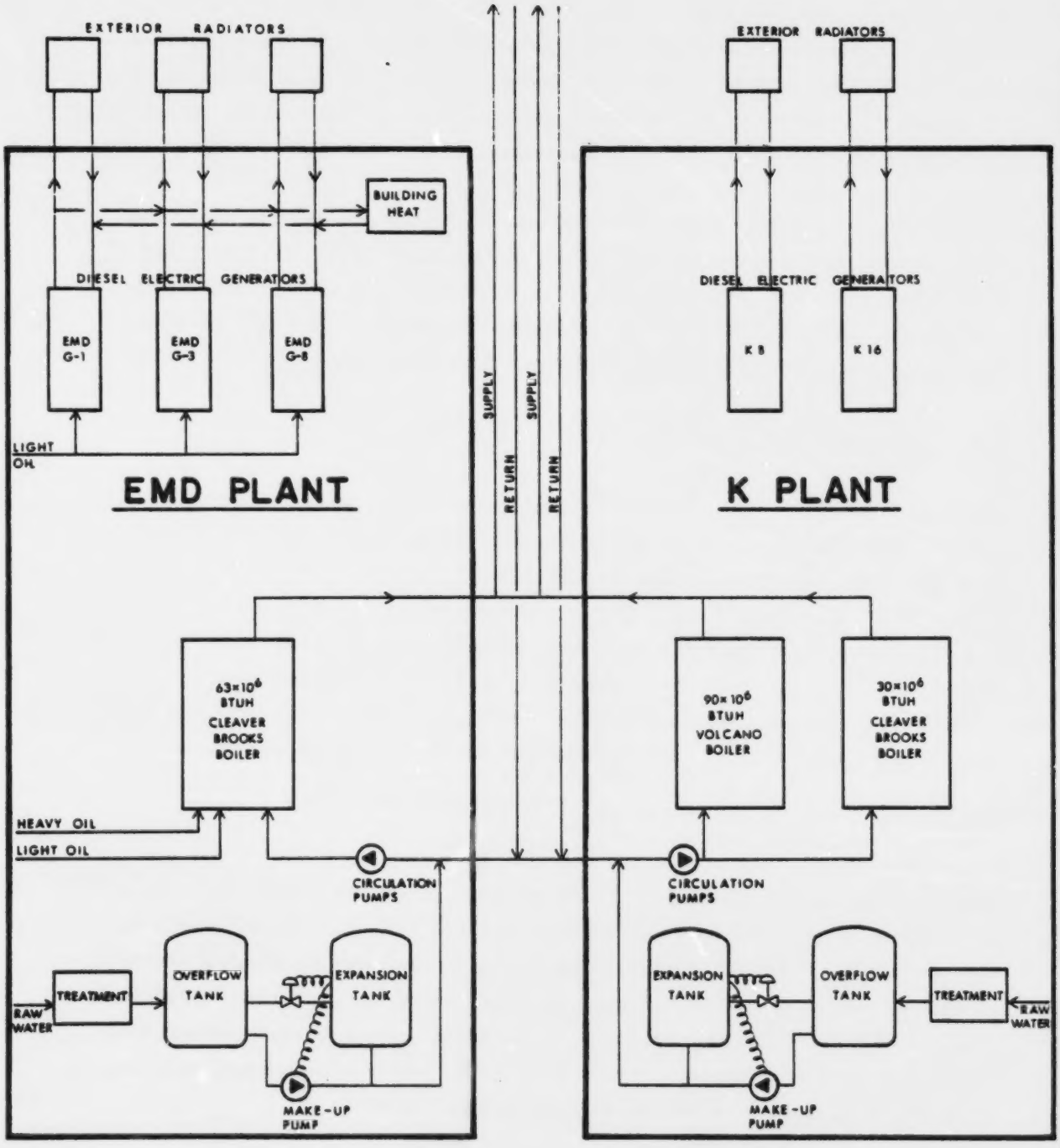
Distribution System

The utilidors which carry HTW mains are nearly all of metal construction, and all are supported on timber piles and timber pile caps. A typical utilidor cross section is shown in Figure 4.

The utilidor pipe mains are schedule 40 welded steel, in sizes from 8-inch down to 1-1/2-inch. They are supported within the utilidor on rollers, to permit free expansion and contraction movement between anchor points and in-line expansion joints. The typical spacing between line anchors is 150 to 300 feet.

A line anchor consists of a large concrete pile cap, in place of the usual heavy timber one, supported by three or four piles. A heavy, monolithic concrete block extends up from the cap, filling the utilidor interior, to the underside of the HTW piping. HTW piping is anchored to the top of the block, by means of welded-on pipe collars, which are in turn welded to steel shoes fixed to the concrete by embedded anchor bolts. Water and sewer mains are run through anchor blocks, by means of embedded sections of pipe. A typical line anchor is sketched in Figure 5.

SIMPLIFIED POWER HOUSE SCHEMATIC



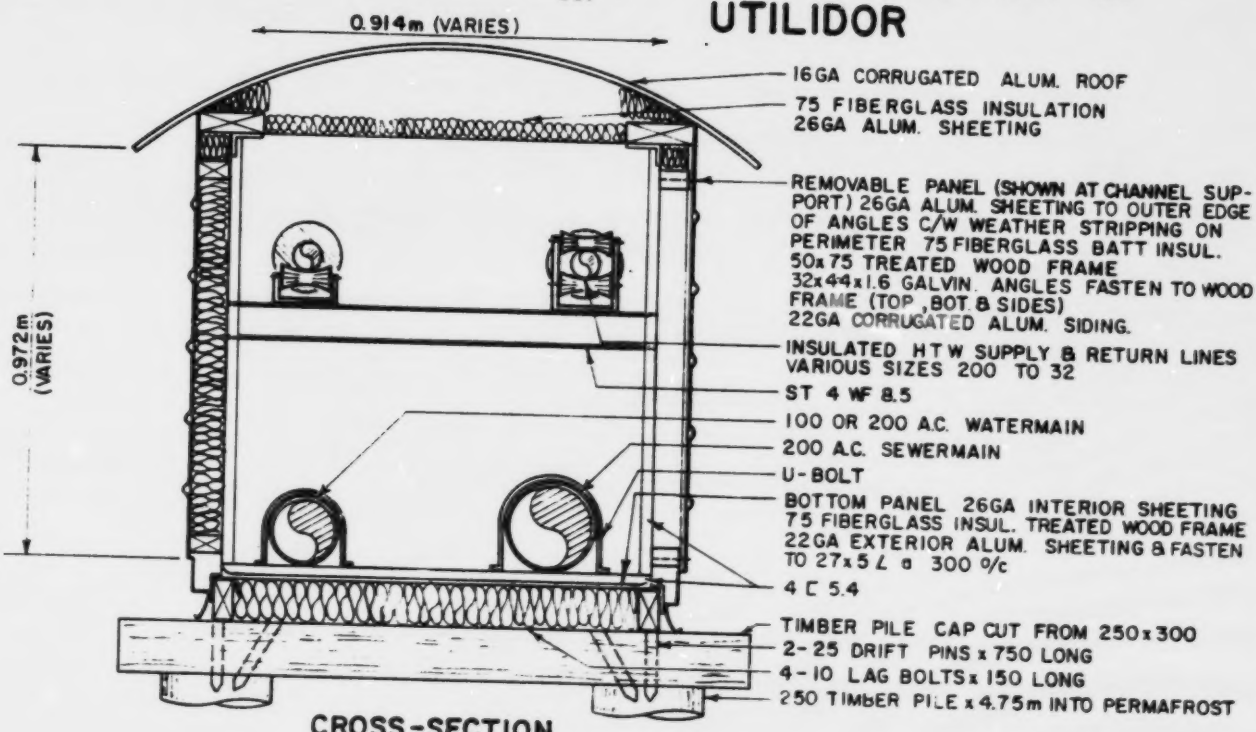
INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

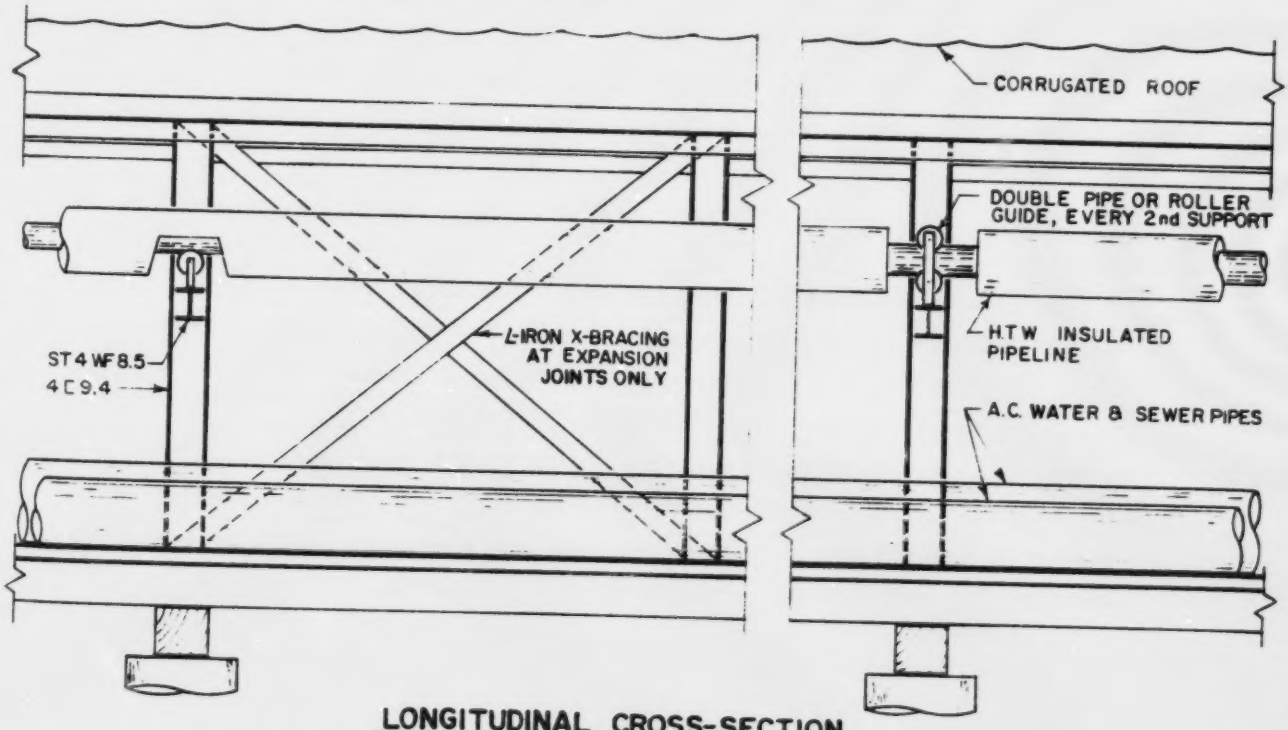
SCALE N.T.S.

VOL. II FIGURE 3

CROSS SECTION OF UTILIDOR


0.914m (VARIES)
0.972m (VARIES)
16GA CORRUGATED ALUM. ROOF
75 FIBERGLASS INSULATION 26GA ALUM. SHEETING
REMOVABLE PANEL (SHOWN AT CHANNEL SUPPORT) 26GA ALUM. SHEETING TO OUTER EDGE OF ANGLES C/W WEATHER STRIPPING ON PERIMETER 75 FIBERGLASS BATT INSUL. 50x75 TREATED WOOD FRAME 32x44x1.6 GALVIN. ANGLES FASTEN TO WOOD FRAME (TOP, BOT & SIDES) 22GA CORRUGATED ALUM. SIDING.
INSULATED HTW SUPPLY & RETURN LINES VARIOUS SIZES 200 TO 32
ST 4 WF 8.5
100 OR 200 A.C. WATERMAIN
200 A.C. SEWERMAIN
U-BOLT
BOTTOM PANEL 26GA INTERIOR SHEETING 75 FIBERGLASS INSUL. TREATED WOOD FRAME 22GA EXTERIOR ALUM. SHEETING & FASTEN TO 27x5 L @ 300 o/c
4 C 5.4
TIMBER PILE CAP CUT FROM 250x300
2-25 DRIFT PINS x 750 LONG
4-10 LAG BOLTS x 150 LONG
250 TIMBER PILE x 4.75m INTO PERMAFROST

CROSS-SECTION


CORRUGATED ROOF
DOUBLE PIPE OR ROLLER GUIDE, EVERY 2nd SUPPORT
H.T.W. INSULATED PIPELINE
A.C. WATER & SEWER PIPES
ST 4 WF 8.5
4 C 9.4
L-IRON X-BRACING AT EXPANSION JOINTS ONLY

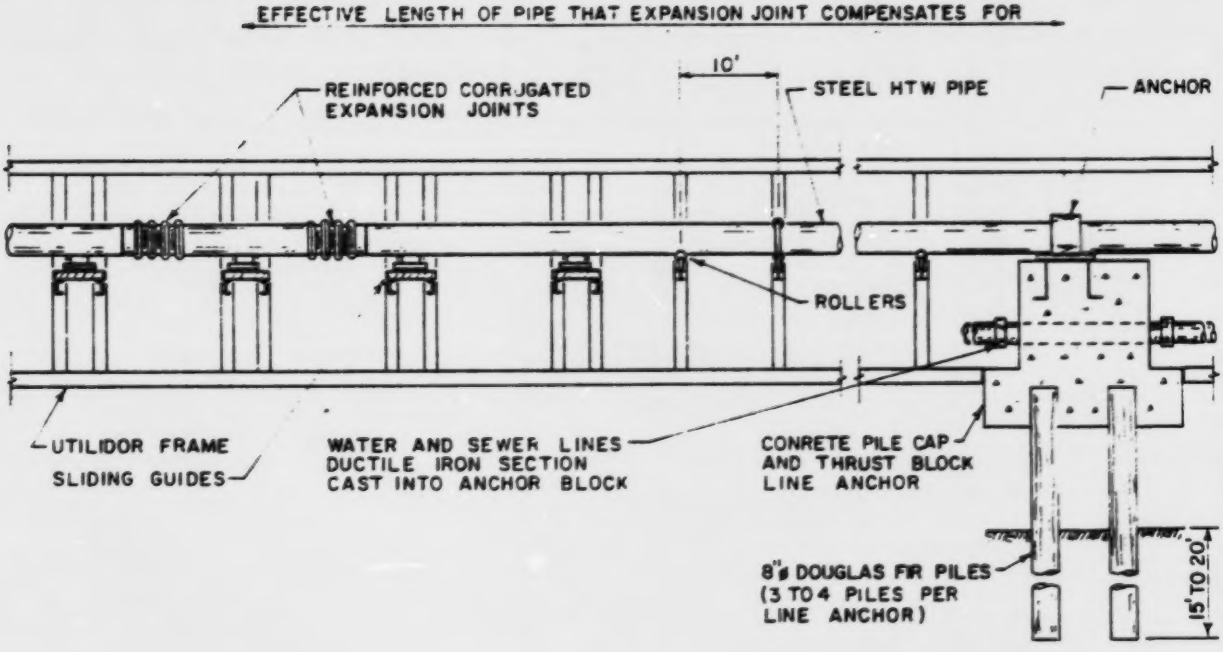
LONGITUDINAL CROSS-SECTION

INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 4

TYPICAL HTW PIPE RESTRAINT DIAGRAM


EFFECTIVE LENGTH OF PIPE THAT EXPANSION JOINT COMPENSATES FOR
10'
REINFORCED CORRUGATED EXPANSION JOINTS
STEEL HTW PIPE
ANCHOR
ROLLERS
UTILIDOR FRAME
SLIDING GUIDES
WATER AND SEWER LINES DUCTILE IRON SECTION CAST INTO ANCHOR BLOCK
CONRETE PILE CAP AND THRUST BLOCK LINE ANCHOR
8"ø DOUGLAS FIR PILES (3 TO 4 PILES PER LINE ANCHOR)
15' TO 20'

NOTE:

DIAGRAMMATIC ONLY
NOT TO SCALE
STEEL FRAMING SHOWN CONCEPTUALLY,
NOT PICTORIALLY

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 5

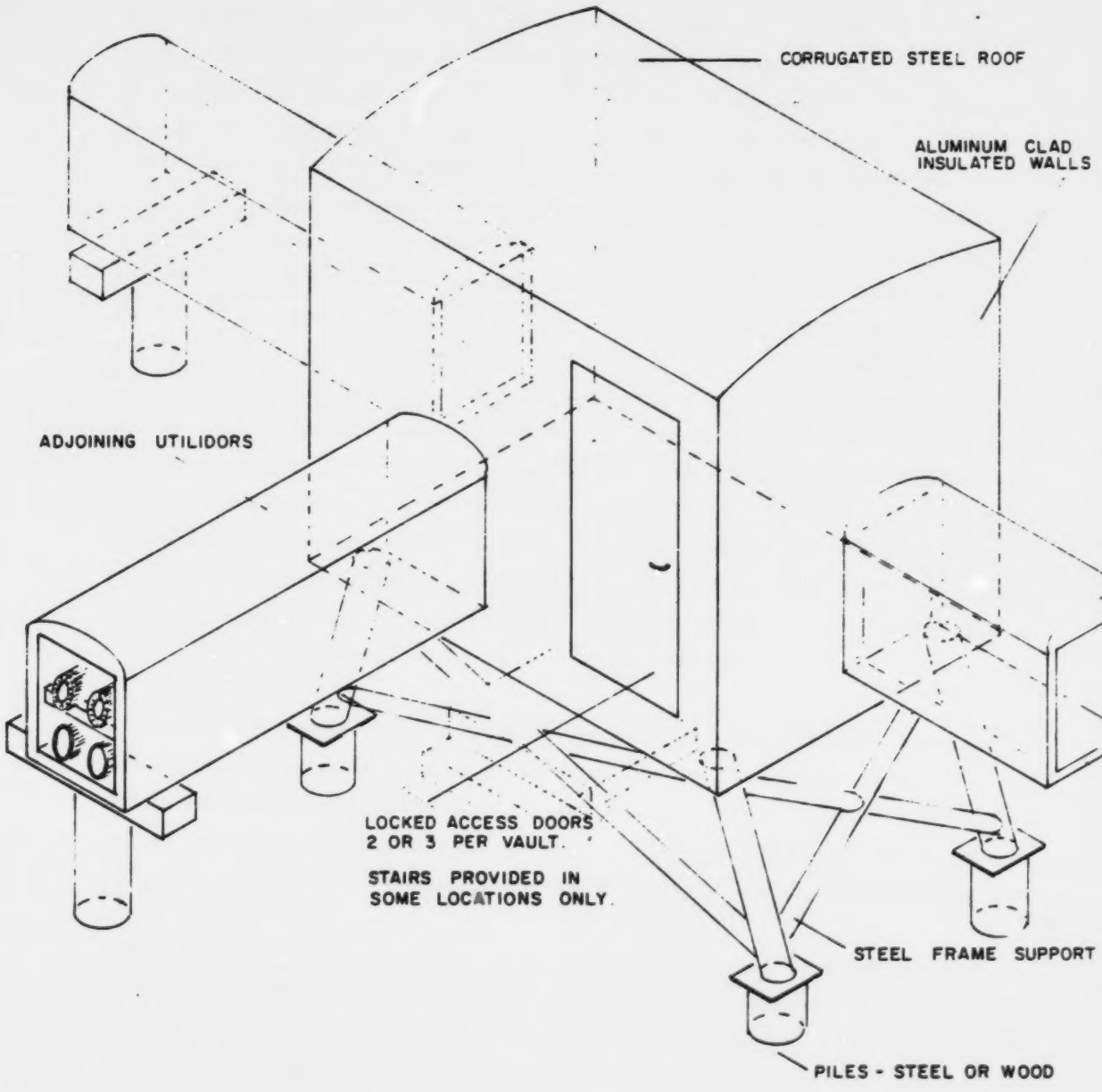
The valves and piping crossovers that occur at junction points require more room than a typical utilidor section provides, so these system features are housed in small metal buildings known as "vaults" or "junctions". The largest of these is about 16 feet square. Most have full headroom, discounting obstructions such as overhead pipes. Like utilidors, vaults are supported well clear of the ground, on piles, to prevent degradation of permafrost and thaw settlement. Many vault piles are steel; some are timber. The usual combined pile cap and floor is of concrete, entended upward where needed to provide pipe anchorage. The building enclosures are insulated metal panels on steel frames. Vaults are windowless, and doors are metal and padlocked. A typical vault is sketched in Figure 6.

Most of the 400 to 500 expansion joints in the system are Flexonics (Flexonics Division of UOP Ltd.) weld end, controlled flexing single and double "high corr" stainless steel bellows units. A small number of joints in 2-1/2-inch mains are loops of high pressure flexible stainless steel hose, fabricated by Hydroflex Ltd. Bowers pipe guides are installed on both sides of expansion joints. Sketches of the Flexonics single and double units, and the Hydroflex loop, are shown in Figure 7.

An analysis of expansion joint traverse (reported in detail in Volume I) has shown that about half of the existing joints in the system are pulled beyond manufacturer's recommended limits during summertime shutdowns for scheduled maintenance. Furthermore, up to 15 percent appear to be overcompressed at normal (supply) operating temperature of 350°F.

The road crossings over the original metal utilidors are small bridges, with concrete abutments and concrete decks. In a small number of crossings of more recent construction, HTW piping is led through a culvert laid in the road bed. In all of the latter type, groundwater infiltration has led to corrosion of HTW piping.

TYPICAL UTILIDOR VAULT

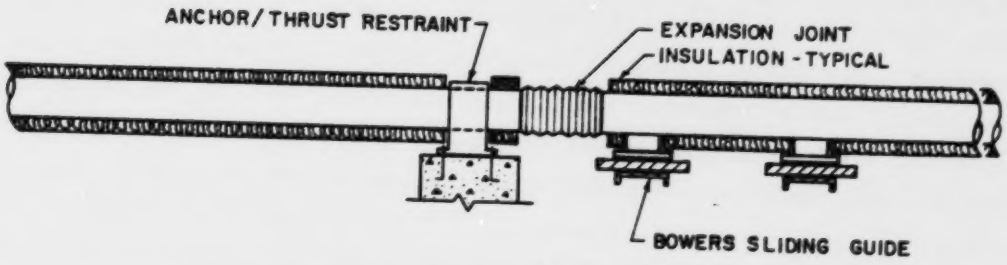

CORRUGATED STEEL ROOF
ALUMINUM CLAD INSULATED WALLS
ADJOINING UTILIDORS
LOCKED ACCESS DOORS 2 OR 3 PER VAULT.
STAIRS PROVIDED IN SOME LOCATIONS ONLY.
STEEL FRAME SUPPORT
PILES - STEEL OR WOOD

INUVIK , NWT

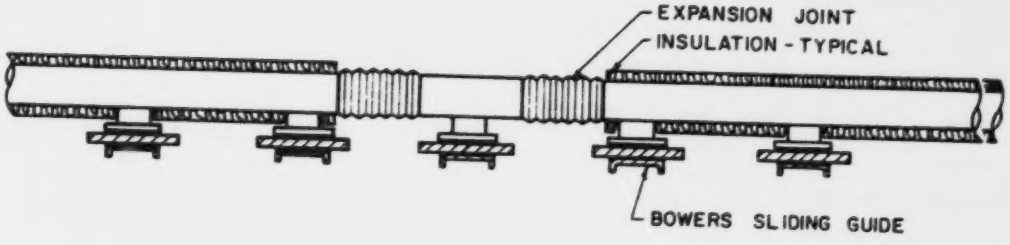
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 6

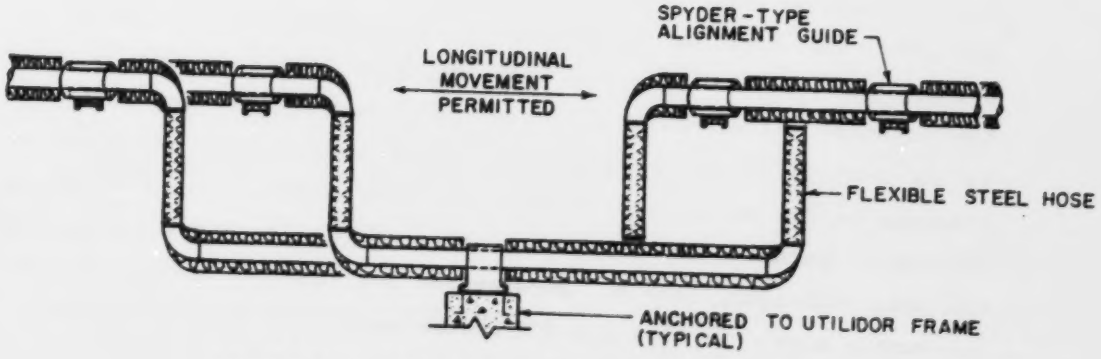
TYPICAL EXPANSION JOINT ARRANGEMENTS



FLEXONICS SINGLE EXPANSION JOINT



FLEXONICS DOUBLE EXPANSION JOINT


SPYDER - TYPE ALIGNMENT GUIDE
LONGITUDINAL MOVEMENT PERMITTED
FLEXIBLE STEEL HOSE
ANCHORED TO UTILIDOR FRAME (TYPICAL)

HYDROFLEX EXPANSION LOOP

NOTE:
DIAGRAMS ARE SIMPLIFIED

INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE : N.T.S.

VOL. II FIGURE 7

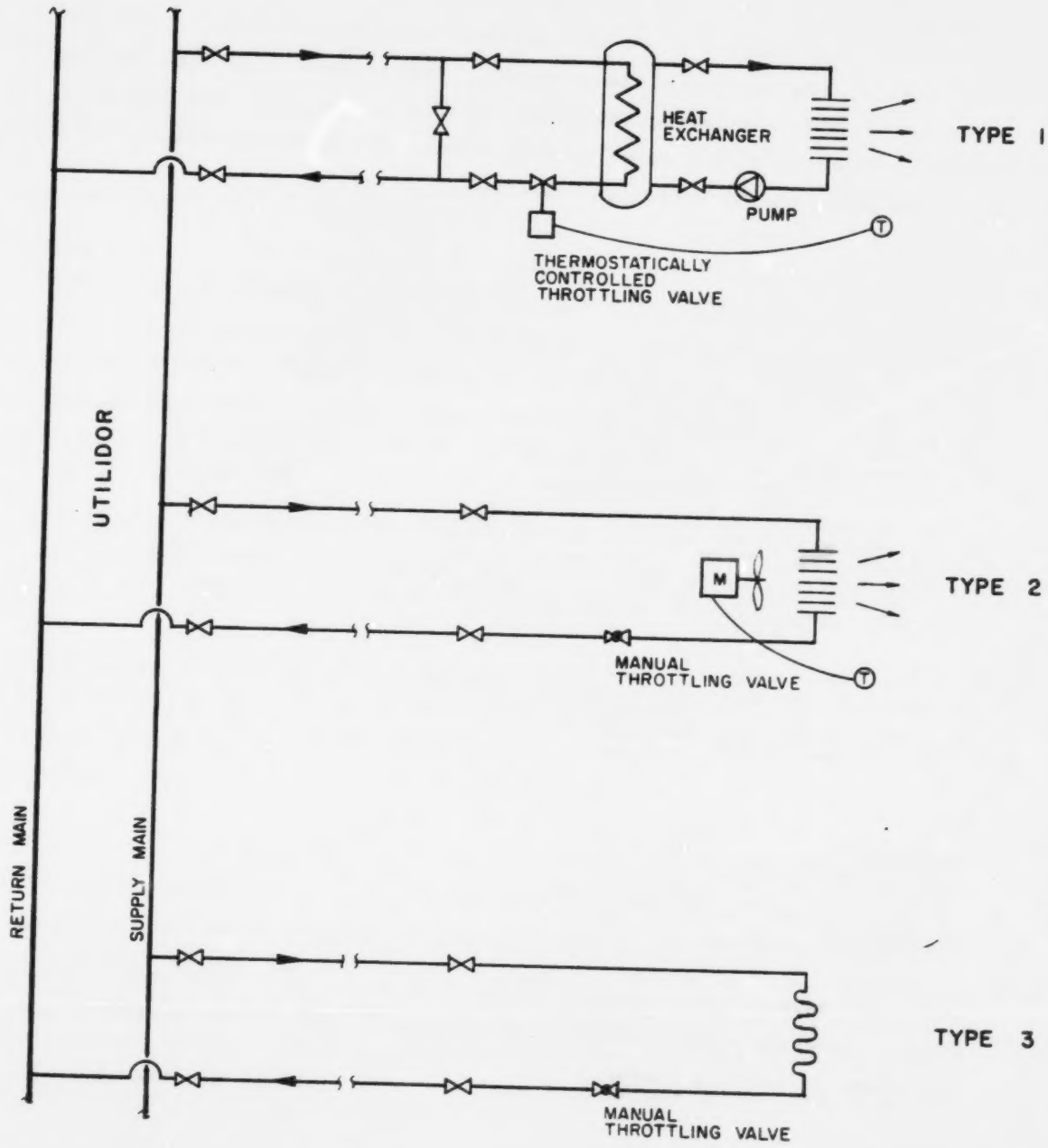
The distribution system is structurally sound and by and large in excellent condition. Defects requiring attention described in Volume I include a small number of rotten piles that need to be replaced or scarfed, a few frost-damaged anchor blocks that need to be rebuilt, and a number of lesser items. The distribution system has been very well protected from corrosion, except in culvert-design road crossings, and pipes and fittings appear to be in essentially new condition. Each year there is need to replace several expansion joints, due to leaking bellows, but expansion joints are the only system components in which there has been need for a significant number of replacements.

Consumer Connections

Consumers take high temperature water from the supply main, extract heat from it in a heat exchanger or other device, and discharge it to the return main. The three different types of consumer connections to the HTW system are shown in Figure 8.

Type 1 is the preferred design, and is by far the most common. Heat from the "primary" (HTW) service line circuit passes to the "secondary" building heating circuit, through the heat exchanger. A typical building circuit operates in the 150° to 200°F range, near atmospheric pressure. The circulation pump operates at a constant rate, so the amount of heat put into the building is controlled by increasing or decreasing the primary (HTW) flow through the heat exchanger. Primary flow is driven by the pressure differential which exists between supply and return lines. It is controlled by a modulating valve which opens or throttles in response to the building thermostat or, more commonly, an aquastat in the secondary system. The modulating valve is placed in the return side of the heat exchanger, because temperatures are somewhat lower there than on the supply side. In 1984 the HTW system served 233 type 1 consumers.

CONSUMER CONNECTION DIAGRAMS



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 8

In type 2, there is no separate secondary heating circuit. High temperature water is piped directly through the building heating pipes, and through unit heaters which have thermostatically controlled fans. The fans control the amount of heat taken. The primary flow rate may be adjusted manually, at infrequent times, to suit the season. The pumphouse and water plant at Hidden Lake, certain warehouses and the Canadian Forces store are among the 18 buildings heated in this way.

Type 3 is the simplest design of all. High temperature water is piped directly through heating coils or heat is simply radiated from the HTW pipes themselves. The rate of hydraulic flow, and therefore heat flow more or less, is controlled by a manually adjusted throttling valve. There are six connections of this type, including NCPC's fuel tank heaters and several utilidette heating loops.

It was recommended in Volume I that certain type 2 connections, and Type 3 circuits heating NCPC's fuel tanks, be replaced with Type 1 systems for reasons of safety.

Characteristics of the consumers now served by the HTW system are described in the next section.

CONSUMERS

Introduction

Technical aspects of consumer connections have been described. This section provides some overview information on numbers of consumers and magnitudes of heating loads.

Information on consumers was obtained from an internal report by NCPC entitled "Inuvik HTW Account Investigation, 1982", from AESL's records of consumers from the 1978 analysis of the HTW system, and from observations in the field. NCPC's regional staff in Inuvik, in particular Mr. G. Red Cheyney, Utilidor Maintenance Supervisor, assisted with field work.

Uses of HTW Heat

End uses of HTW heat include

- building heating,
- heating of domestic hot water in buildings, and
- miscellaneous "system" uses, including heating of NCPC's heavy fuel, heating of some building spaces and domestic water in NCPC's plant complex, direct heating of water in the municipal water distribution system and in water storage reservoirs to prevent freezing, and heating of utilidettes.

Heat used to heat main utilidors and vaults has been classified as "lost", for the purposes of the study, even though it serves at least in part a necessary purpose in keeping uninsulated water and sewage mains from freezing.

The amount of heat required for building heating, and certain other uses, is directly dependent on outdoor temperature. On the other hand, the amount used for water heating is probably fairly independent of season, unless large amounts of hot water are used in winter to keep building sewer pipes from freezing. Heavy fuel is heated to 200°F at all times of the year for proper operation of burner nozzles, but the quantities of fuel used, and the rate of heat loss from fuel supply pipes, are less in

summer than in winter. Five utilidette heating loops are "wild", that is, uncontrolled except for the shutoff valves in the utilidor at the main taps. It is believed that they run winter and summer.

The approximate distribution of heating loads between building heating, domestic hot water heating, and system uses, in winter and in summer, is shown in Table 2.

TABLE 2

USES OF HTW HEAT

Classification	February		July	
Mean Temperature	-30°F		59°F	
	MMBH	Pcnt.	MMBH	Pcnt.
Building Heat	52.6	88	7.7	64
Domestic Hot Water	3.9	6	3.9	32
System	3.5	6	0.5	4
Total	60.1	100	12.1	100

Notes:

(a) MMBH is millions of BTUs per hour.

(b) Table 2 excludes losses in generation and distribution.

NCPC also classifies its customers as "government" and "non-government". A different billing rate applies to each group ($16.65/MMBH and $15.30/MMBH respectively). The division of load between the two is shown in Table 3.

TABLE 3

CLASSIFICATION OF CUSTOMERS

Use	Government, Pcnt	Non-Government, Pcnt	Total
Building Heat	78.8	21.2	100.0
Domestic Hot Water	90.2	9.8	100.0

Building Heating

Building heating is by far the largest use of HTW heat, and it is also the use which is most sensitive to change through, for instance, heat conservation renovations, or gain or loss of customers through perceived differences in the cost of heat from alternate sources.

Of the 257 connections to the HTW system catalogued in the course of the study, 243 are for building heating, or both building and domestic hot water heating. An approximate classification of consumer buildings by occupancy is show in Table 4.

TABLE 4

HTW CONSUMER BUILDING OCCUPANCY

Occupancy	Buildings	Dwelling Units	Heat Load
			Pcnt.total
Single family	110	110	12
Row House	68	300	25
Apartment	14	unknown	12
Other	51	0	51
Total	243	-	100

Notes:

(a) "Row Houses" are two to eight units

(b) "Apartments" are apartment buildings. The number of apartments was not determined in most cases.

(c) "Other" includes commercial, institutional and recreational occupancies: offices, hotels, stores, warehouses, schools, hospital, the arena, etc.

(d) Numbers shown in the table are approximate.

It can be seen that loads are quite widely distributed among a large number of buildings. The largest single demand is the Hospital, at 4950 MBH at -50°F, which is about 7 percent of the total heat load of all buildings. The ten largest buildings (in terms of heat load) together account for about 33 percent of the total. It is interesting that only two of these ten, the MacKenzie Hotel and the Bay Store, are located in Inuvik's downtown core. The others, which include the hospital, two schools, two school residence buildings, two DND buildings and the Mountainview Apartments, are rather widely distributed in the townsite and over the HTW system.

SYSTEM OPERATION AND CONTROL

Introduction

As outdoor temperatures vary, the amount of heat being generated by the duty boiler must constantly adjust to match demand. Occasionally during the year it becomes necessary for operations staff to change to a larger or smaller boiler, to match heat generation capacity to load.

The capacity of the distribution system as a whole could, if necessary, be altered to an extent by bringing additional circulation pumps on line. Similarly, the distribution of heat between individual loops of the

distribution system could, if necessary, be altered to an extent by throttling the valves at branch junctions to change the hydraulic balance of the system.

Finally, each consumer controls the amount of heat transferred from the HTW system to his own equipment, in most cases by means of an automatic flow control valve.

The purpose of this section is to outline the means and methods used to control the district heating system. The fact that a change in any hydraulic control affects the entire HTW network, and leads to further changes throughout the system, is also discussed.

Boiler Control

Boiler controls automatically modulate fuel and combustion air inputs to maintain the temperature of HTW leaving the boiler at 350°F.

Boiler Scheduling

In principle, best efficiency can be obtained by following, to a reasonable degree, a firing plan designed to take best advantage of the optimum efficiency range of each boiler. However, the efficiencies of the boilers over their 50 to 100 percent load ranges are very flat, the variance generally being less than one percent. Furthermore, as described later in the report, the efficiencies of the different boilers are not greatly different, probably being within two percent or so of each other in overlapping ranges. Therefore, it would actually be counterproductive to change boilers frequently in response to small variations in load, or ones of short duration. Plant operating records show that NCPC's practice is to change boilers only when necessary to match operating range to demand, or for maintenance or other convenience reasons. In general, the

large (90 MMBH) Volcano boiler is used throughout most of the winter. The small (30 MMBH) Cleaver Brooks is used in summer.

Thermal load in millions of BTU's per hour, the annual duration of each load level in hours, and the capacities of boiler and useful combinations of boilers are all shown together in Figure 9. A hypothetical firing schedule which has been used in analysis of system efficiency is shown in Table 5. Available data on boiler efficiency is presented in a later section.

TABLE 5

HYPOTHETICAL BOILER FIRING SCHEDULE

Load	Boiler	Capacity	Capacity Used
8 to 25 MMBH	CB D60	30 MMBH	26.7 to 83.3%
25 to 55 MMBH	CB DL94	63 MMBH	39.7 to 87.3%
55 to 79 MMBH	Volcano	90 MMBH	61.1 to 87.8%

Notes:

(a) MMBH is millions of BTUs per hour.

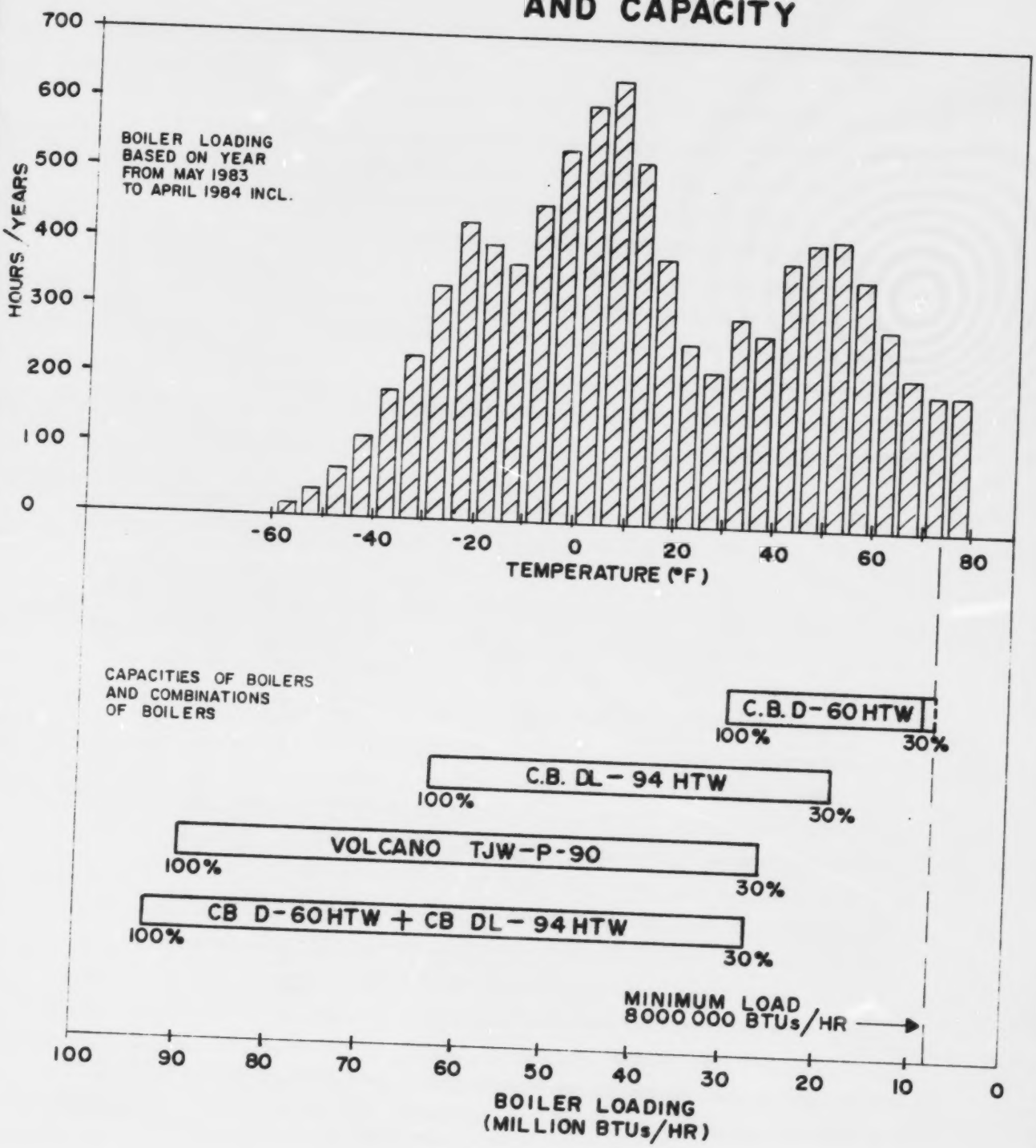
(b) Load rarely if ever exceeds 70 MMBH, with existing consumers.

(c) Load is the "external" load on the system, including heating of fuel tanks, but excluding in-plant uses, which amount to 2 to 5 percent of external load. Plant loads are discussed later in the report.

Pump Scheduling

There are several distribution system circulation pumps located in each powerhouse, connected in parallel. One pump is run at all times, to maintain circulation. NCPC has not found it necessary to run more than one pump at any time, at current load levels.

BOILER LOADING AND CAPACITY



INUVIK , NWT

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Hydraulic Balancing Between Flow Loops

There are valves in the distribution system, at junction points and elsewhere. It is understood, from discussions with NCPC personnel and field observations, that none of these are used for throttling or balancing. Similarly, all of the crossovers between supply and return mains, which could be used for system balancing at some cost in efficiency, are normally closed. Flows in the system are defined by the hydraulics of the pipes themselves, both mains and consumer pipes, and most importantly, by the operation of the primary flow control valves in consumer connections.

Consumer's Controls

As described earlier, most consumers' systems control the amount of heat taken from the HTW system by varying the flow of high temperature water through the primary side of a heat exchanger, or through the primary heating coils in the case of domestic hot water heaters. A sensor monitors the temperature of secondary (building heating) water leaving the heat exchanger, or of potable water in the domestic hot water tank, and the primary control valve responds as needed to maintain temperature at the set level.

As described earlier, there are a few consumer connections which do not modulate according to demand. These represent a fairly small proportion of total heat consumption, and have only minor influence on the behavior of the district heating system as a whole. Nevertheless, all control systems have been modelled correctly in computer analyses.

Control Interactions

The amount of heat required by a consumer at any time depends on the size and thermal characteristics of his building, and on ancillary loads such

as hot water heating. The amount of heat actually drawn at any moment is determined by

- the hydraulic and thermal characteristics of his heat exchanger, which are essentially fixed,
- the rate of circulation flow through the secondary (building circuit) side of the heat exchanger, also more or less fixed,
- the temperature of returned secondary water entering the heat exchanger, which becomes somewhat cooler when the demand for heat increases,
- the temperature of high temperature water supplied to the primary side of the heat exchanger, and
- the rate at which high temperature water is supplied to the primary side of the heat exchanger.

The first three parameters are fixed, within quite narrow limits. High temperature water leaves the duty boiler at a controlled temperature of 350°F, so the fourth parameter is also fixed, at least near the powerhouse. However, supply temperature must decline along the flow path from the powerhouse, since the HTW mains lose heat to the utilidor interiors, which then flows to the outdoors and to water and sewer mains. Temperature loss has been determined by analyses, and confirmed in the field by measurement of pipe temperature. It has been found not to be particularly significant. It amounts to a maximum of 5°F , from 350° to 345°F, in the built-up area of the community, and to 12°F at Hidden Lake, under ambient temperatures of -55°F. Therefore, supply temperature, too, is essentially constant, insofar as control of heat supply to consumers is concerned.

It follows that the remaining variable which actually controls the flow of heat to a consumer is the rate of HTW flow through the consumer's heat exchanger. This is in turn a function of two parameters: the pressure differential between the supply and return mains serving the consumer, and the position of his primary flow control valve. Pressure differential may vary widely, since it is in turn a function of the position of consumers' control valves throughout the system. Valve position also ranges widely, from fully open to fully closed.

The interdependence between each individual consumer, his neighbors, consumers in general, and the main distribution system is a fundamental characteristic of the HTW system. It is the basis of the very complex behaviour of the HTW system, and the consequent difficulty of modelling it realistically.

To illustrate the system's response to a change in temperature, consider it in some state of initial balance. Each consumer's control valve has steadied at a setting which will provide just the amount of high temperature water flow needed to replace the heat being lost by the building. If the temperature now falls, the buildings lose more heat, and more is drawn from each building's heating circuit. The return water temperature declines, which tends to increase the flow of heat across the heat exchanger, but not enough to compensate for the increased loss. A fall in secondary circuit temperature is detected. The control system opens the primary HTW control valve a little more, reducing pressure loss across the valve, and thereby increasing HTW flow through the heat exchanger.

Meanwhile, similar responses are taking place in buildings throughout the system. Theoretically, the ports of all control valves have widened fractionally. The result is that there is a decrease in the pressure loss, or pressure differential, between supply and return networks

throughout. The system moves to a slightly different point on the circulation pump's curve, at lower head and higher flow.

Naturally, the flow increase is less than what would be expected considering the effects of valve operations alone. The increased inflows brings an increase in head loss due to friction, friction loss being proportional to the square of velocity.

If it happened that each consumer's valve was calibrated to move just enough to give the needed additional heat based on pre-existing pressures, then a further increment of opening would be needed to gain the full amount of additional flow needed, at the reduced pressure. The second increment would be different at different places in the system, because the cumulative effect of increased friction losses would be greatest at points that are hydraulically most distant from the ciculation pump. In theory, the system would re-balance to the new temperature in a series of iterations. Naturally, such an idealized response does not occur, except perhaps in the thought processes of Hydrotherm.*

The actual behaviour of the system is of course much more transient and complex, since loads continually change in response to changes in temperature, changes in building thermostat settings, cyclic demands for hot water and other factors.

Clearly, it would involve a substantial amount of iterative calculation to determine the changes that would occur if the system were to move from balanced conditions at one temperature, to balanced conditions at another, a few degrees away. The calculation of the initial balance at the first temperature is a more formidable task, since the calculation begins with estimated control valve settings and a completely unbalanced system.

*Hydrotherm III: Computer program which analyses hydraulic flows and heat transfer in a district heating system.

PART II

PREPARATION FOR ANALYSIS OF EXISTING SYSTEM

INTRODUCTION

The HTW system and the complexity of its behaviour were described in Part I. Part II describes the steps taken and methods used in analyses of capacity and efficiency, and analyses of potential improvements. Part III deals with the findings of analyses, and recommended changes.

Major steps in analyses of existing capacity and efficiency included

- gathering of data
- compilation of system information onto base plans and schematics,
- preparatory analyses, intended to generate data and relationships needed for overall analyses,
- initial hydraulic and thermal analyses of the complete system, used to calibrate system data sets against actual operating records,
- hydraulic and thermal analyses of the system's capacity to serve existing consumers, and existing consumers plus large new loads at selected locations, at the design cold temperature,
- hydraulic and thermal analysis of net annual efficiency under current conditions, and the effect of potential minor renovations on efficiency,

- valuation of energy, and

- assessment of the cost effectiveness of minor renovations intended to enhance efficiency.

Data and system information, methods, and certain intermediate results and conclusions which may be of interest are summarized in this section.

GATHERING AND COMPILATION OF DATA

Plant and Facilities

Information on powerhouse installations, the HTW distribution system and consumers' equipment was obtained from

- engineering drawings of the two powerhouses, and available drawings of utilidors (from NCPC),

- records from 1977 inspections of all consumers' facilities (AESL), and the current list of consumers still using the HTW system (NCPC)

- field inspections, and discussions with NCPC's head office and regional staff

Simplified schematic drawings of piping systems of interest in both powerhouses were prepared, and checked in the field. Drawings covered systems supplying heavy and light fuel to engines and boilers, fuel heating, high temperature water circulation and makeup, engine cooling, and existing in plant uses of heat taken from both high temperature water and engine cooling systems. These drawings are not included in the Report, owing to their size.

Base plans of the HTW distribution system were prepared, at a scale of 1:1000. These show supply and return mains, pipe sizes, valves, crossovers, anchor points, expansion joints, vault piping, and consumers' taps. Information was compiled from previous base plans covering parts of the system, construction drawings and field notes. The distribution system base plans have not been checked extensively in the field, since the task would require a man-year or two; they are not free of minor errors and ommissions. Again, these have not been included in the report owing to size.

Various utilidor and utilidette cross sections are found throughout the HTW system. Drawings were obtained, or sketched when necessary. Pipe diameters, utilidor dimensions, pipe and structure insulation type and thickness, joint sealing and other information was recorded. A base plan was indexed to show the sort of cross section found on each segment of the system.

Another base plan was used to record the location of each of the system's 257 consumers, using consumer identification numbers assigned for the purpose of the study. A consumer data list was compiled, covering such factors as location, supply and return piping diameters and lengths, control method, sizes and other information about the control valves and heat exchanger. The file also contains operational data and characteristics, which are described in the next section.

Operational Characteristics

Information on the operational characteristics of the district heating system was obtained from

- monthly records of heavy and light fuel used by boilers and by electric generators, 1982 through 1984,

- continous automatic chart records of HTW supply and return temperatures and fuel flow,

- data sheets and other information provided by manufacturers of boilers, pumps and other major pieces of equipment,

- weather logs, including daily maximum and minimum temperatures, May 1, 1983 to April 30, 1984, kept by NCPC,

- NCPC internal report entitled "Inuvik HTW Account Investigation, 1982" and NCPC lists of consumers and consumer locations, and

- discussions with NCPC staff.

The uses made of the information are described below.

PREPARATORY ANALYSES

Boiler and Pump Characteristics

The efficiency of each Cleaver Brooks boiler was calculated, at different loads, using information provided by the manufacturer, and efficiency-load curves drawn. The efficiency-load curve for the Volcano boiler was estimated, data not being available. Efficiencies are recorded in Table 6.

TABLE 6

BOILER EFFICIENCY

Boiler	Capacity	Efficiency at Stated Percent of Load		
	MMBTU/hr	50%	75%	100%
CB D60	30	81.9	81.5 E	81.1
CB DL94	63	83.3	83.3	82.8
Volcano	90	83 E	83 E	82 E

Notes:

(a) Efficiencies listed have been calculated from data supplied by manufacturers. "E" means estimated, by interpolation, or from NCPC's fuel consumption records. Boilers are not usually run at less than 50% load.

Characteristic load - volume curves for circulation pumps are shown in Figure 10.

Utilidor Heat Loss Factors

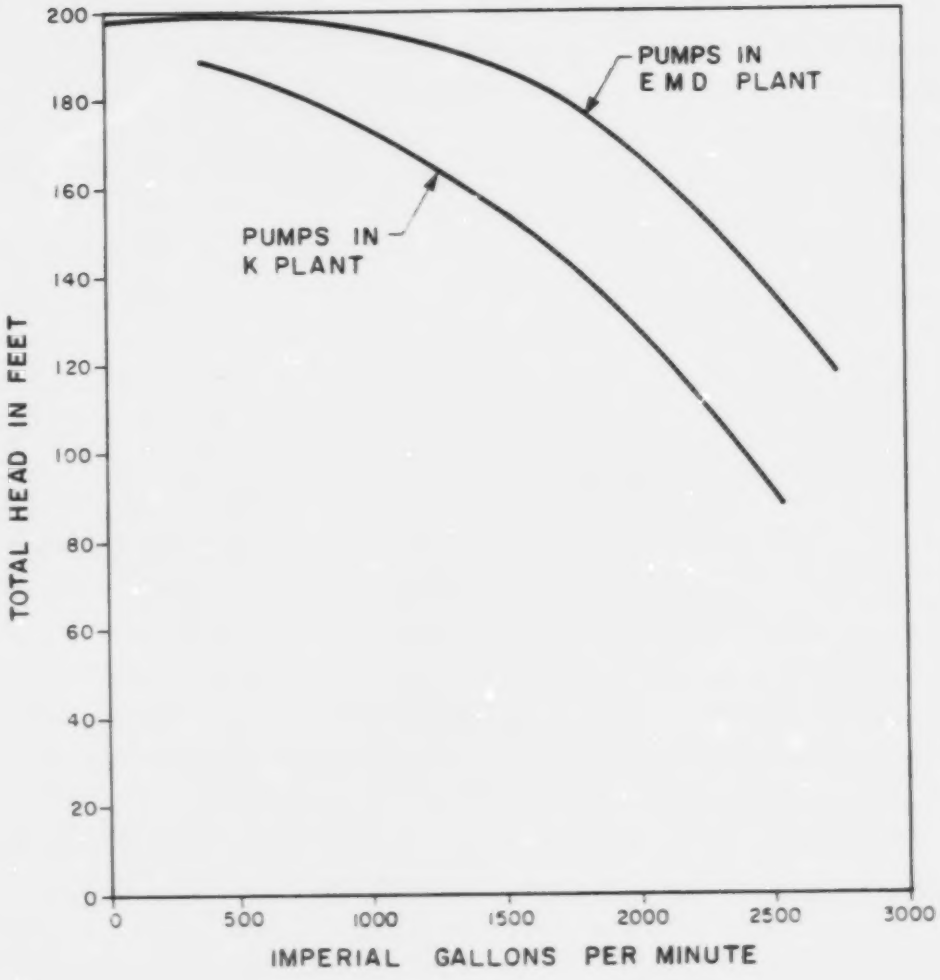
The thermal resistance of the walls, floor and ceiling of each class of utilidor was calculated, and used to calculate an equivalent thermal envelope size and heat conductivity.

Design Temperature for Analyses of Capacity

January design temperatures listed for Inuvik in the Supplement to the National Building Code of Canada, 1980, are -46°C (-50.8°F), 2.5% occurrence, and -48°C (-54.4°F), 1% occurrence.

Using round figures, the choice of design temperature for analysis of the HTW system would appear to between -50°F and -55°F. An occurrence of 2.5%

HEAD FLOW CURVES FOR HTW DISTRIBUTION PUMPS



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in January would represent a total duration in that month of 18.5 hours. February is nearly as cold, so the average annual exposure to temperatures below 50°F might be in the order of 35 to 40 hours. Similarly, the exposure to temperatures below -55°F might average 15 hours per year.

As will be discussed later, any shortfall in the distribution system's capacity to satisfy a large overall demand for heat will probably be concentrated on a small number of consumers, rather than being distributed over most or all. Since this would lead to unacceptable conditions for the unlucky few, the lower temperature, -55°F, has been chosen as the design cold temperature for analyses of capacity.

Temperature Profiles

Most of the heat delivered by the HTW system is used to heat buildings. Consequently, most of the load varies, hourly and seasonally, as a function of outdoor temperature.

The distribution system's efficiency and energy losses vary with outdoor temperature. Consequently, to determine net annual efficiency, it is necessary to consider both the efficiency of the system within different increments of the full range of outdoor temperature, and a temperature profile giving the annual duration of each temperature increment. Similarly, analyses of system performance for some chosen month requires a temperature profile for that month.

Choice of Data Period for Temperature Profiles

A temperature profile may be constructed from long term average temperatures, from temperature data from groups of years selected according to some criterion, or from temperatures recorded over a single year. Obviously, for the purpose of estimating heating system

performance, a profile representative of long term average conditons would be desirable.

In this study, however, it was decided to construct a profile from data for a single year. This would make it possible to calibrate computer model results against actual plant operating data, for the same year. A review of NCPC's plant operating data found the records for the period May 1, 1983 to April 30, 1984, are fairly complete and consistent, and this period was chosen. Being recent, the 1983-84 data should be reasonably representative of current operating experience.

As it happens, the total heating impulse for the chosen data period is 18,570°F-days below 65°F, which compares well with the long term figure of 18,313°F-days (10174°C-days) below 64.4°F (18°C).

Synthesis of Temperature Profiles

Temperature profiles were constructed from available records of daily maximum and minimum temperatures, by the following procedure:

1. Hourly temperatures were synthesized by fitting a sine wave function between recorded daily maximum and minimum temperatures.

2. The ambient temperature range, from -60° to +100°F, was divided into increments, referred to as "bins", of 5°F.

3. The total number of hours of occurrence of temperatures within each 5°F bin was determined, for each month and over the entire year.

4. The twelve monthly profiles and the one full year profile were tabulated.

The temperature profile for the selected data year is shown in Figure 11.

Valuation of Heat

The cost of a unit of heat energy is the aggregate of the capital, operations and maintenance costs of the system which generates and delivers it. The cost of fuel is a major component.

Obviously, capital and every other cost varies according to the design of the system, and to an extent with its size. A small system serving a single building is usually more costly, per unit of energy delivered, than one serving an entire community. Even the price of fuel, or equivalent thermal units of fuel, depends or may depend on the supplier, the type and class of fuel, the quantity purchased, and the method and cost of storage at Inuvik and delivery to the consumer's tankage.

The current value of heat is the cost of producing and delivering it by existing facilities. The district heating system constitutes one major class of facility, and the large number of self-contained, oil fired, hydronic and warm air systems another. The billed cost of HTHW heat is a matter of record, although it must be acknowledged that the billed cost may not wholly reflect total actual costs. The total cost of providing heat by the variety of private systems in existence would of course vary from building to building. Estimates of the cost of heating by self-contained systems are discussed in a later section.

The optimum value of heat is the least cost for which it can be produced and delivered to the point of use. Obviously, a fundamental objective of this study is to determine as nearly as possible what that optimum value is, and how to achieve it. However, for economic analyses reported in the sections immediately following, it was considered that the billed cost of HTW heat is the best indicator of current value. Billing rates which NCPC has applied during the last five years are shown in Table 7.

OUTDOOR TEMPERATURE DISTRIBUTION BASED ON YEAR 1983-1984

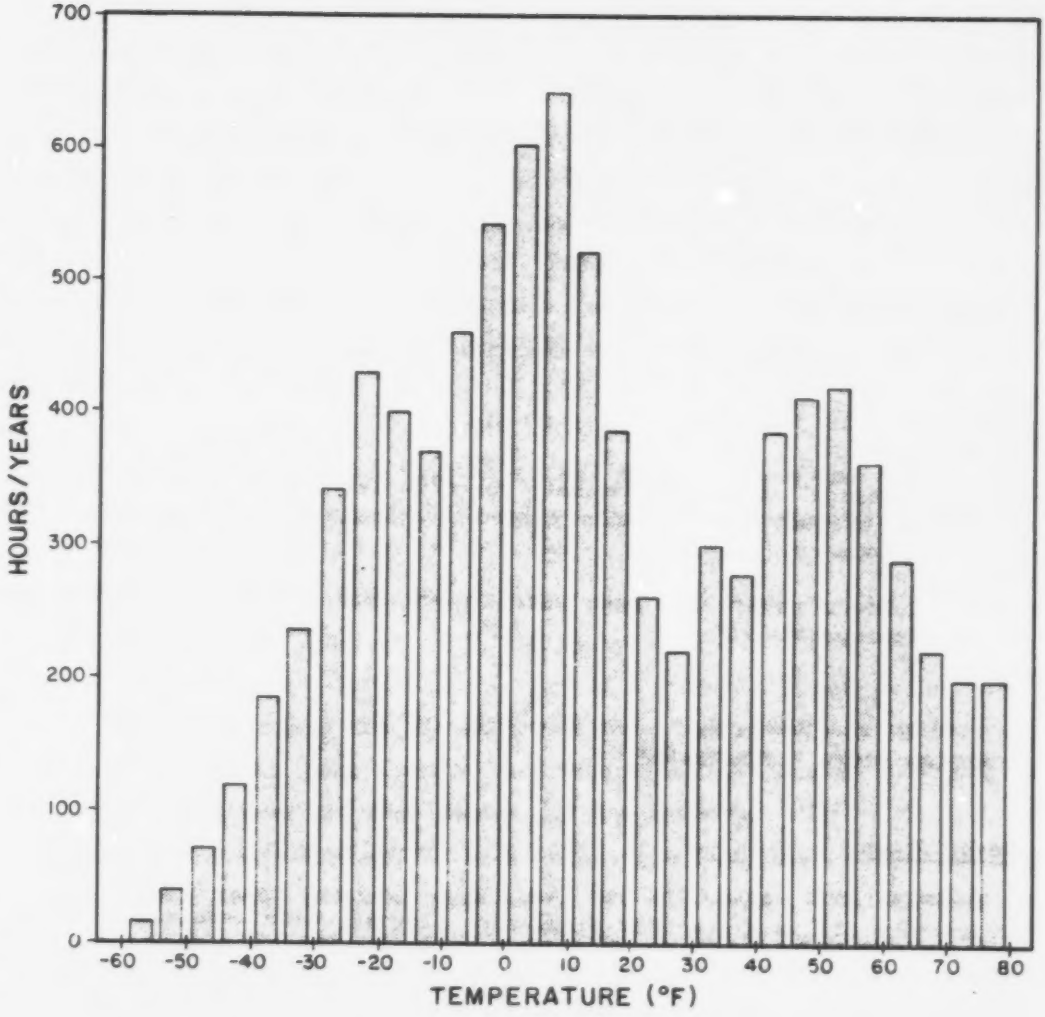

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TABLE 7

HTW BILLING RATES, 1979-1985

PERIOD	RATE, $/MMBTU		
	Government	Non-Government	Average
1979 - 1980	8.60	7.48	8.39
1980 - 1981	9.80	8.53	9.56
April 1981 to Nov. 10, 1981	11.81	10.54	11.57
Nov. 11, 1981 to April 1982	13.44	12.17	13.20
April 1982 to June 10, 1982	11.81	10.54	11.57
June 11, 1982 to October 11, 1982	13.44	12.17	13.20
October 11, 1982 to April 1983	16.81	15.54	16.57
April 1983 to April 1985	16.65	15.30	16.39

Notes:

(a) "Average" is the approximate weighted average, calculated according to proportion of load carried by Government and Non-Government consumers.

(b) Current rates have been used in economic analyses when considered appropriate.

COMPUTER MODEL "HYDROTHERM"

Description

Hydrotherm III is a computer simulation program which determines hydraulic flows and temperatures throughout a liquid medium heat distribution system. It was written primarily to analyse the performance of district heating systems, such as Inuvik's HTW system, but will also solve flows and temperature in municipal water systems and other piping networks.

The program's hydraulic analysis module

- simulates the pipe network, and can use different roughness factors for each pipe,

- simulates pumps, valves, check valves and other devices using hydraulic response curves, and using discontinuous functions when appropriate,

- calculates Reynolds number for each pipe, determines whether flow is laminar or turbulent, and chooses between the Darcy and Colebrook equations for calculation of head loss,

- generates a series of linear equations, using the first derivative of the head loss equation, and solves the resulting matrix,

- iterates hydraulic calculations until balance is achieved within chosen limits, and then calls the temperature analyses module.

The temperature analysis module

- proceeds along the direction of flow throughout the system, calculating heat losses and determining beginning and end temperatures for each segment of the network,

- uses heat balance equations to calculate the interior temperature of each segment of utilidor, and heat losses to water and sewer mains and the outdoors,

- calculates the maximum heat available to each consumer, according to the stated design temperature drop in primary

(HTW) water, and the maximum rate at which high temperature water would flow through the heat exchanger with the control valve (if any) fully open, at prevailing system pressures,

- calculates the building heat required by each consumer according to the building heating load factor and the stated outdoor temperature, and adds domestic hot water and any other load,

- determines the heat withdrawn by each consumer: equal to the lesser of demand and maximum available,

- calculates the control valve setting required to obtain the heat withdrawn, at the stated HTW temperature drop and prevailing HTW system pressures, and

- iterates heat and temperature calculations until balance is achieved within stated limits.

Since changes in control valve settings will affect hydraulic flows and pressures throughout the system, the hydraulic program is called again. The entire process is repeated, until the system is balanced in all respects.

Input Data

Input data were prepared, from information and analyses described earlier.

Two consumer input files were prepared. In one, all 257 consumers were represented separately. In the other, nearby consumers having similar characteristics were grouped, to produce a set of 122 equivalent

consumers. Reducing the number of consumers substantially speeded computer runs, and greatly reduced the volumes of output data, without significant loss of precision.

Output Data

Significant items in the output data file include

- actual flow rates through each segment of pipe and each piece of equipment, and the maximum flow rate available to each consumer with a fully open control valve at prevailing system pressures,

- upstream and downstream pressures and temperatures at each segment of pipe and each piece of equipment,

- the heat required by each consumer, the heat taken, and the maximum available at prevailing pressures and temperatures, and

- totals of heat supplied, heat required and heat actually taken by consumers, total heat deficiency (if any), system heat losses, number of consumers adequately supplied and number undersupplied, and similar summary parameters.

COMPUTER RUNS FOR CALIBRATION

Introduction

It is often the case when doing computer modelling of a large system, that there is little opportunity to test and calibrate the model and its input data against actual behavior in the field. Predictions must therefore be

taken with trust and used with caution. In the case of Inuvik's district heating system, operating records provided some opportunity for calibration, albeit limited to the powerhouse, since flows, pressures and temperatures are either not measured or not routinely recorded in the distribution system.*

Scope of Investigation

As described earlier, the operating period from May 1,1983 to April 30, 1984 was chosen to represent system performance, after a review of operating records.

NCPC's staff at Inuvik assisted with the review of data, and provided copies or loaned needed information.

Data Tests

Data files from 1977 analyses of the HTW system by Hydrotherm I were updated, over a series of runs, to 1984 conditions. Hydraulic characteristics of boilers, pumps and other devices were altered as necessary to match data from manufacturers. Consumers' heat loads were altered to match NCPC's new data, set out in NCPC's report of the 1982 HTW system account analysis. Runs using the complete inventory of consumers were compared against runs at the same outdoor temperature using the shorter list of equivalent consumers, and results were found to be quite similar.

*Spot measurements of temperatures in the distribution network were taken in the course of field work. The data helped to confirm modelling accuracy.

Calibration Test

A review of operating records found that the one available test of the simulation model's accuracy would be to compare estimated fuel use against NCPC's monthly fuel use summary.

Estimates were made of fuel consumption by the HTW system in each month during the chosen data year, for comparison against NCPC's fuel use records, by the following procedure:

1. Runs were made to determine the total heat distributed and lost by the distribution system, under current conditions, at 70°F, 10°F, -40°F and -55°F. The resulting temperature load relationship was found to be nearly linear, and was characterized as a straight line.

2. The temperature profile for the month was integrated with the temperature-load function to determine the number of hours of operation in each increment of distribution system load.

3. Each distribution system load level was increased to account for in-plant uses of heat, such as air and fuel heating, to arrive at total boiler output load. In calculating increases, due consideration was given to outdoor temperatures and concurrent monthly electrical load. (Total energy flows within each powerhouse were analysed for the purpose of waste heat recovery and energy optimization studies. These subjects are dealt with later).

4. The boiler firing schedule and the table of boiler efficiencies, reported earlier, were used to convert each level of boiler output load into an equivalent level of boiler input load, still in BTU's per hour, at a known duration.

5. The boiler input loads, all of known duration, were converted to energy input loads, in BTU's per month. Monthly loads were tabulated.

6. Recorded fuel consumption was converted to monthly energy use, using the energy equivalent of heavy fuel.

The energy load calculated for each month considered is compared to recorded consumption in Table 8, and in Figure 12.

TABLE 8

COMPARISON OF CALCULATED FUEL USE TO RECORDED USE

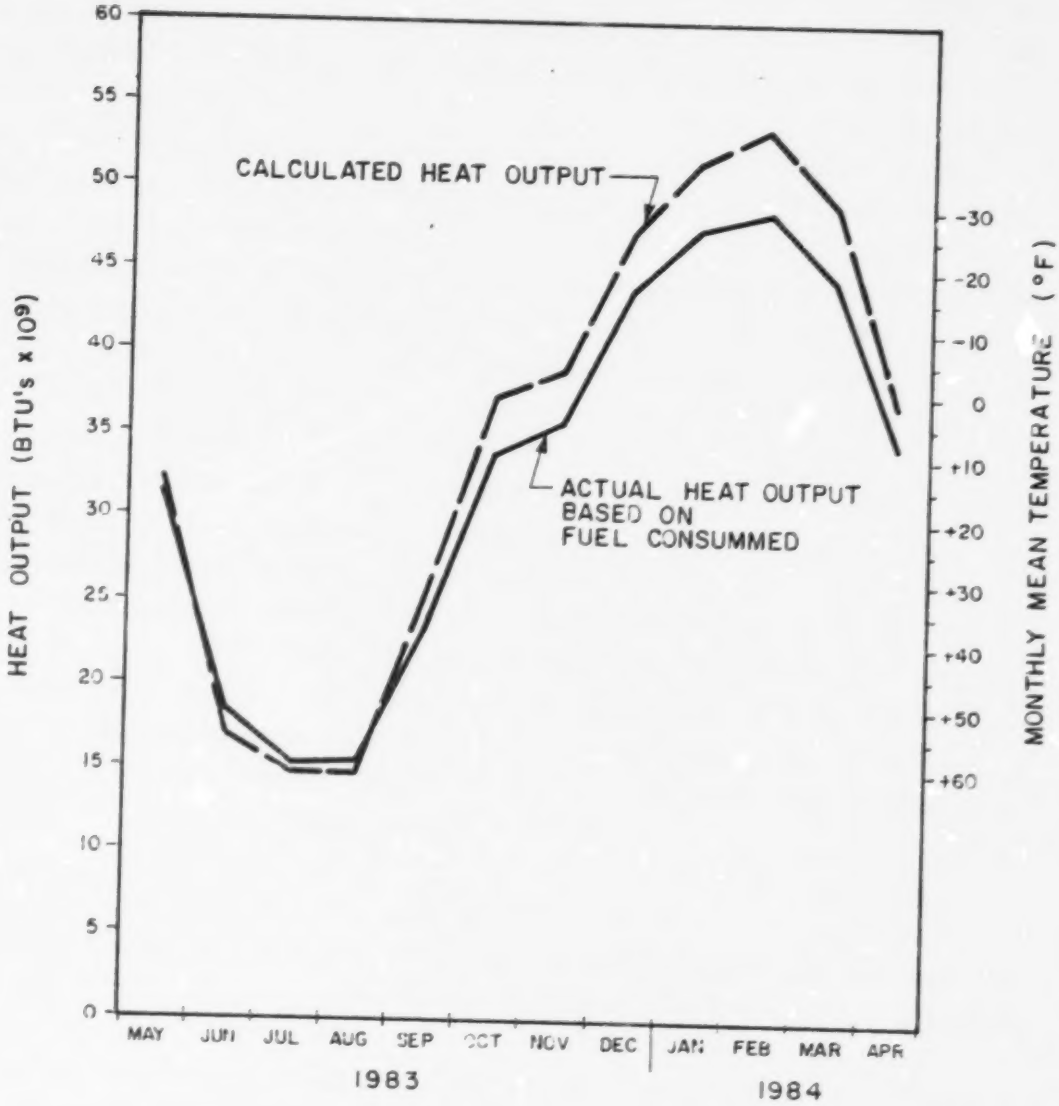
Year	Month	Est'd MMBTU	Actual MMBTU	Pcnt
1983	May	32430	31740	2.2
"	June	17060	18380	-7.8
"	July	14910	15230	-2.1
"	August	14910	15700	-5.3
"	September	25850	23420	10.4
"	October	37500	34220	9.6
"	November	39160	36190	8.2
"	December	47280	43720	8.1
1984	January	51640	47550	8.6
"	February	53260	48630	9.5
"	March	49120	44760	9.7
"	April	37130	34600	7.3

Notes:

(a) Pcnt is percent difference between calculated and actual

(b) Actual is the thermal equivalent of fuel used, based on 182,400 BTU/ig.

FUEL USE CALIBRATION TEST



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It will be seen that the model understates fuel use by up to 8 percent in summer, and overstates by 8 to 10 percent in winter. It is likely that one factor contributing to the winter overestimate was the use of 75°F as the indoor temperature for buildings. Probably 70°F would be more representative of a daytime temperature of 72°F and a nightime temperature set several degrees lower. In fact, considering electrical energy inputs to homes, through lighting, stoves and other appliances, it might be reasonable to use an indoor temperature of 65°F.

Use of an interior temperature of 65°F would reduce the February heat load by 8 percent, October by 7.5 percent, September by 18.2 percent and August by 30.5 percent. Better agreement would be achieved in winter, at the expense of worse in summer.

While it can be seen that better agreement in end results could be achieved in various ways, for instance by reducing the calculated heat loads for each building and reversing the estimate of domestic hot water loads, there are no independant data available to check the reasonableness of such manoeuverings. It was decided, therefore, not to attempt to improve the calibration at this time, lest the model actually be made, in hidden ways, less rather than more representative of the true behaviour of the system.

Conclusions

The one available test appears to confirm that the system model and input data are calibrated within reasonable tolerance.

PART III

ANALYSIS OF EXISTING SYSTEM AND POTENTIAL IMPROVEMENTS

INTRODUCTION

Work done in preparation for the analysis of the existing district heating system was described in the preceding section. Part III describes the analysis of the system's capacity to carry existing and increased loads, its efficiency, and means of improving efficiency. The options of abandoning or extending district heating, and the effects that such developments as heat conservation retrofit in buildings, heat metering and availability of natural gas might have on system loading and economics are also addressed.

ANALYSIS OF CAPACITY

Introduction

The amount of uncommitted heat which could be taken at some place in the distribution network, for a new customer or for one whose heat loads have increased, will be limited by either

- the thermal capacity of the boiler,
- the hydraulic capacity of the circulation pump, or
- the hydraulic capacity of the main pipes.

The objective of this section is determine whether the HTW system's capacity is fully used by existing consumers, or if it would be capable of carrying significantly greater load.

Scope of Investigation

The hydraulic and thermal characteristics of boilers, circulation pumps and consumer equipment were obtained, as described earlier. Consideration was given to the range of flow velocities in mains which might be acceptable. System performance with existing consumers at outdoor temperatures of -40°F and -55°F was simulated in computer runs. Boiler and pump performance, and flow velocities, head losses and residual head differentials in the distribution mains were assessed. The capacity available to each consumer was compared to capacity required and to the amount of heat actually taken.

Further simulations were made at -40°F and -55°F with large new loads added at selected points in the distribution system. The output was evaluated in the same way.

Boiler Capacity Limits

The thermal output of a boiler is equal to the heat content of the fuel it uses, less heat lost up the stack and elsewhere. Burner nozzle orifices are calibrated to the fuel to be used, so that net output should equal the boiler's capacity at the maximum rate of fuel flow. Consequently, a boiler's maximum output under operating conditions should equal but not exceed rated capacity, aside from adjustment and calibration tolerances and variation in fuel quality.

The rated capacities of the boilers in NCPC's powerhouses have been listed earlier; 30, 63 and 90 MMBH. Considering possible outage of the largest single unit, the system's reliable boiler capacity under normal conditions would be 93 MMBH.

The limiting output of an HTW boiler is reached when the boiler is just able to reheat returned water to the intended supply temperature of 350°F., with maximum fuel inflow. If the water flow rate is increased further, or if the temperature of returned water decreases, the heat added by the boiler will no longer be sufficient, and supply temperature will fall. If the amount of heat being taken by consumers does not change, then the water which is supplied at less than 350°F will eventually return at a temperature even farther below normal return temperature, leading to a further drop in supply temperature. This cycle of gradually declining temperatures throughout the system would continue indefinitely, if nothing else changed. Change would occur, however. Buildings unable to fullfil heat needs would cool toward outdoor temperature, which would reduce the overall rate of heat loss. Eventually the entire system, including consumers, would stabilize at some lower range of temperatures where total load was again equal to boiler output.

NCPC reported that the 63 MMBH Cleaver Brooks boiler "carried" the full load of the system at a temperature as low as -48°F. However, supply temperature dropped to 325°F, which raises the question as to whether the system was fully carried. Allowing 9.5 percent overstatement of system loads by the model as calibrated, the calibrated system load at this temperature would be about 69 MMBH.

Pump Capacity Limits

The circulation pump maintains the flow of heated water in the distribution network. It operates against head losses due to friction in the boiler, supply and return mains and consumers' piping, and head lost through consumers' control valves. Head losses across valves, flow velocities and pipe friction losses continually vary in response to control valve modulation, the rate of flow being a function of the pump's characteristic head-volume curve.

Three identical circulation pumps are installed in parallel in the K plant. Two other pumps, identical to each other and slightly but not significantly different from the K plant pumps, are installed in parallel in the EMD plant. With parallel installation, bringing more pumps on line will increase volume, but combined head will not exceed the maximum head of a single pump. Operating curves for circulation pumps have been reported earlier.

However, in Inuvik's system, the distribution pumps are sized so that they cannot be overrun even at very high consumer demand levels. If this were not the case, then it would simply be necessary to arrange controls to start a second pump when demand exceeded a certain level.

Distribution Network Capacity Limits

The amount of heat that a pipe in the distribution network can carry is determined by the rate of hydraulic flow, and the amount by which HTW temperature will fall in passing through consumers' heat exchangers. The overall temperature change from supply to return, measured at the powerhouse, is normally in the range of 70 to 80°F; 81°F at -55°F outdoor temperature. Flow velocities in pipes of course vary throughout the system.

Some consideration has been given to the maximum velocity of flow that might be considered acceptable. There is no specific limit on the acceptable range of velocity, but designers avoid velocities above 10 ft/sec in order to preclude rapid erosion damage to pipes and fittings, and to reduce the likelihood of severe waterhammer. In fact, most systems are designed for maximum normal velocities in the order of 5 ft/sec, or less, to minimize friction losses and attendant pumping costs and pressure losses.

In Inuvik's system, each consumer depends on the difference between pressures in the supply mains and the return mains, provided by the circulation pump, to drive high temperature water through a heat exchanger. The maximum heat inflow a consumer can obtain is determined by the maximum HTW flow available to him, with his control valve wide open. Flow is in turn determined by the pressure differential at his location in the network, which is equal to pump head, less head lost in passing through the boiler, the control valve, and supply and return mains and other piping.

Friction loss is proportional to the square of velocity, so available pressure differential across a consumer's connection decreases as flows in the network increase. Stated differently, increased flows decrease the amount of capacity available to each consumer, based on the piping and heat exchanger currently installed. The greatest effects are most likely to be felt in the more distant branches of the distribution network.

Friction losses have other effects as well. They largely determine the hydraulic balance of the distribution network as a whole. The system's designers have achieved reasonable balance without use of throttling valves, in part through careful choice of main pipe diameters.

The relative importance of friction losses at different velocities is shown in Table 9. The head loss is given in feet per thousand feet of steel pipe, and the diameters listed are representative of the diameters found in the HTW system. As mentioned earlier, friction loss increases in proportion to the square of velocity, and the rapid increase in loss as velocity increases can be seen.

The distance along the utilidor from the powerhouse to, for example, the Block 47 row housing is 5300 feet, and the hospital 4400 feet. The return flow paths are the same lengths. The circulation pump has a shut-off head of just under 200 ft., and the system usually runs it in the 170 to 190 foot range.

TABLE 9

RANGE OF FRICTION LOSSES IN UTILIDOR MAINS

Diameter	Head Loss, Ft/1000 ft			
Velocity	2.5 ft/sec	5 ft/sec	7.5 ft/sec	10 ft/sec
1.5 in	19	70	151	258
4 in	6.1	22	48	83
6 in	3.7	14	29	51
8 in	2.6	9.8	21	36

Table 10 shows the capacities of the same pipes,to deliver heat, at the same flow velocities, with a temperature drop of 81°F.

TABLE 10

HEAT DELIVERY BY UTILIDOR MAINS

Diameter	Heat Delivered, 81 F drop, MMBH			
Velocity	2.5 ft/sec	5 ft/sec	7.5 ft/sec	10 ft/sec
1.5 in	670	1330	2000	2660
4 in	4160	8320	12500	16600
6 in	9440	18900	28300	37800
8 in	16350	32700	49000	65400

Notes:

(a) The temperature difference between supply and return mains, at the powerhouse, at an outdoor temperature of -55°F, has been calculated to be 81°F.

The distribution system has two main branches, both of which originate at the powerhouse with 8 inch supply and return mains. Therefore, the maximum heat flow near the powerhouse, if a flow velocity of 10 feet per second would be considered acceptable, would be 130,000 MMBH, far above the limit imposed by boiler capacity.

Hydraulic Overload

As described earlier, the pressure differential between supply and return mains at every point in the system varies, constantly, as the hydraulic balance of the system readjusts to changes in settings of consumers' control valves. The pressure differential at any place in the system must remain high enough to drive adequate flow through consumer's connections. It must also stay within a range suited to reasonably fine control by modulation of their control valves.

As mentioned earlier, flow velocities and capacities throughout the system are defined by the hydraulic interactions between all system components; the circulation pump, mains, consumer's pipes and consumer's control valves. This section provides some description of these interactions and a description of system behaviour if hydraulic capacity is exceeded.

For example, a drop in outdoor temperature increases each building's rate of heat loss. The ensuing cooling is detected by the building's heat control system, which responds by fractionally increasing the opening of the HTW control valve. The rate of flow through the primary side of the heat exchanger increases, and consequently the rate of heat inflow also increases.

If outdoor temperature continues to fall, the point will be reached where one or more consumers' valves are fully open. If temperature falls beyond this point, those consumers with fully open valves will not be able to increase HTW flow as needed to cover the further increase in heat loss. In fact, the system will give them progressively less flow. The reason for this is that other consumer's valves, still having reserve capacity, are continuing to open, and to allow increasing quantities of high temperature water to flow from supply mains to return. This allows the pressure differential between supply and return mains to decrease. The flow to consumers whose valves cannot open to compensate for this also decreases, magnifying whatever heat deficiencies have already begun to be felt.

Therefore, a hydraulic failure of the system would be expected to fall most heavily, in its initial stages at least, upon those consumers in the more distant ends of the distribution system who have least reserve capacity in their heat exchangers.

Assessment of Capacity with Existing Consumers

Computer runs were made at outdoor temperatures of -40°F and -55°F, with all existing consumers represented individually.

Runs were also made with the set of combined, equivalent consumers, at 70°F, 10°F, -40°F and -55°F. As indicated earlier, results with the two consumer data sets, individual and combined, were essentially the same.

It was found, as would be expected, that the system delivers sufficient heat to all existing consumers. The total system load at -55°F, including utilidor losses, was calculated to be 78.7 MMBH, and the flow rate at the powerhouse 1560 lgm. The calibration test indicates that actual loads are 9 to 10 percent less; about 71 MMBH.

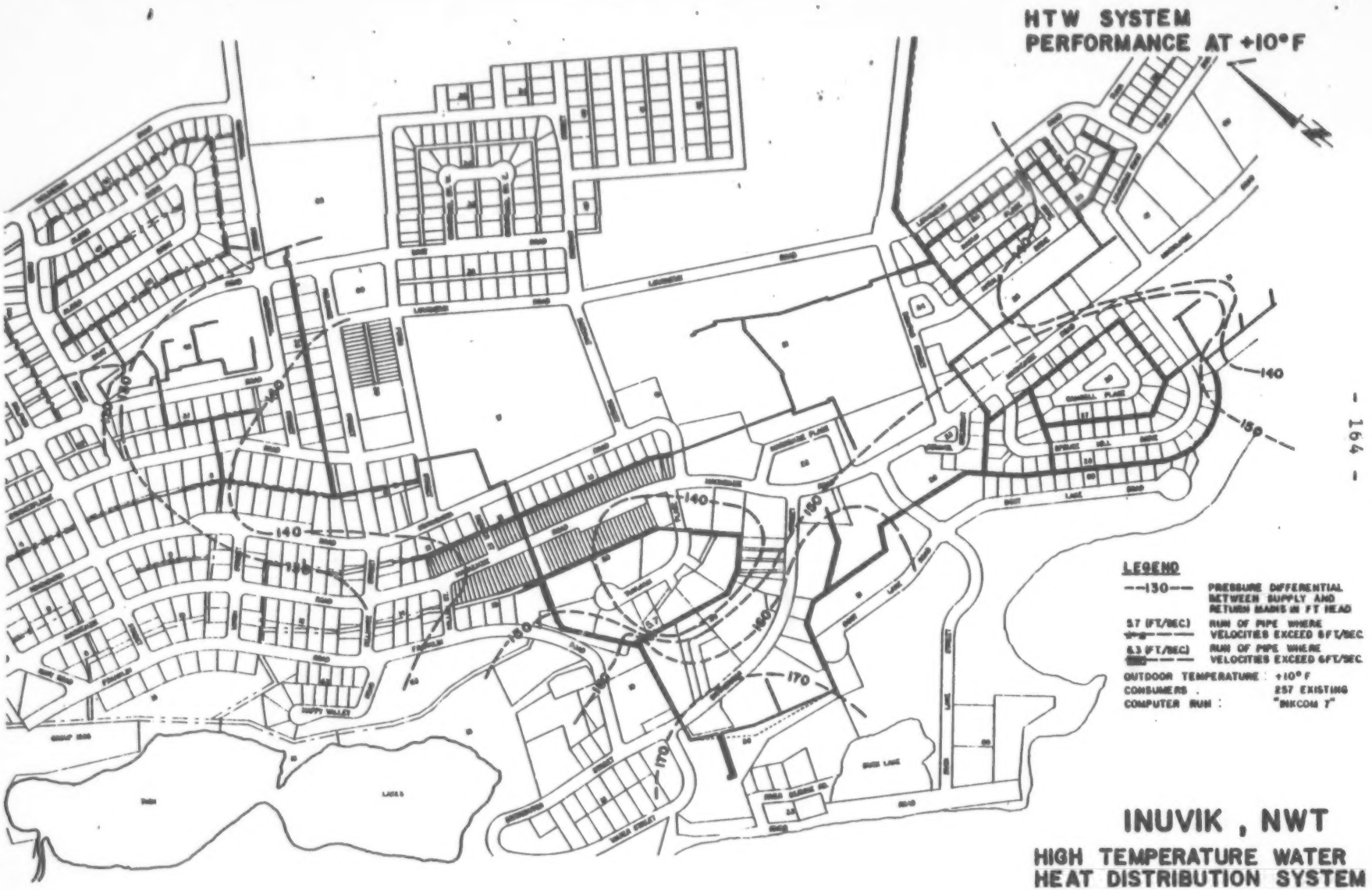
The importance of pressure differential between supply and return mains has been described, and the pressure changes which occur through this progression of outdoor temperatures are of interest. Figures 13, 14 and 15 show pressure differential contours throughout the system at 10°F, -40°F and -55°F. Pipe runs in which flow is restricted, leading to relatively large pressure drops and potential disadvantage to consumers downstream, are highlighted. Incidentially, flows in the system at 70°F are slow, and pressure drops are slight, so no figure has been done for that temperature.

The figures show very well the tendency for pressures at the two extremities of the system, northern and southeastern, to decline toward zero at the high loads caused by low outdoor temperatures. The charts suggest that while there may be considerable reserve capacity in central zones of the network, additional loading might impair the system's ability to deliver heat to its more distant customers. Accordingly, additional simulations were made to test the effect of large new loads.

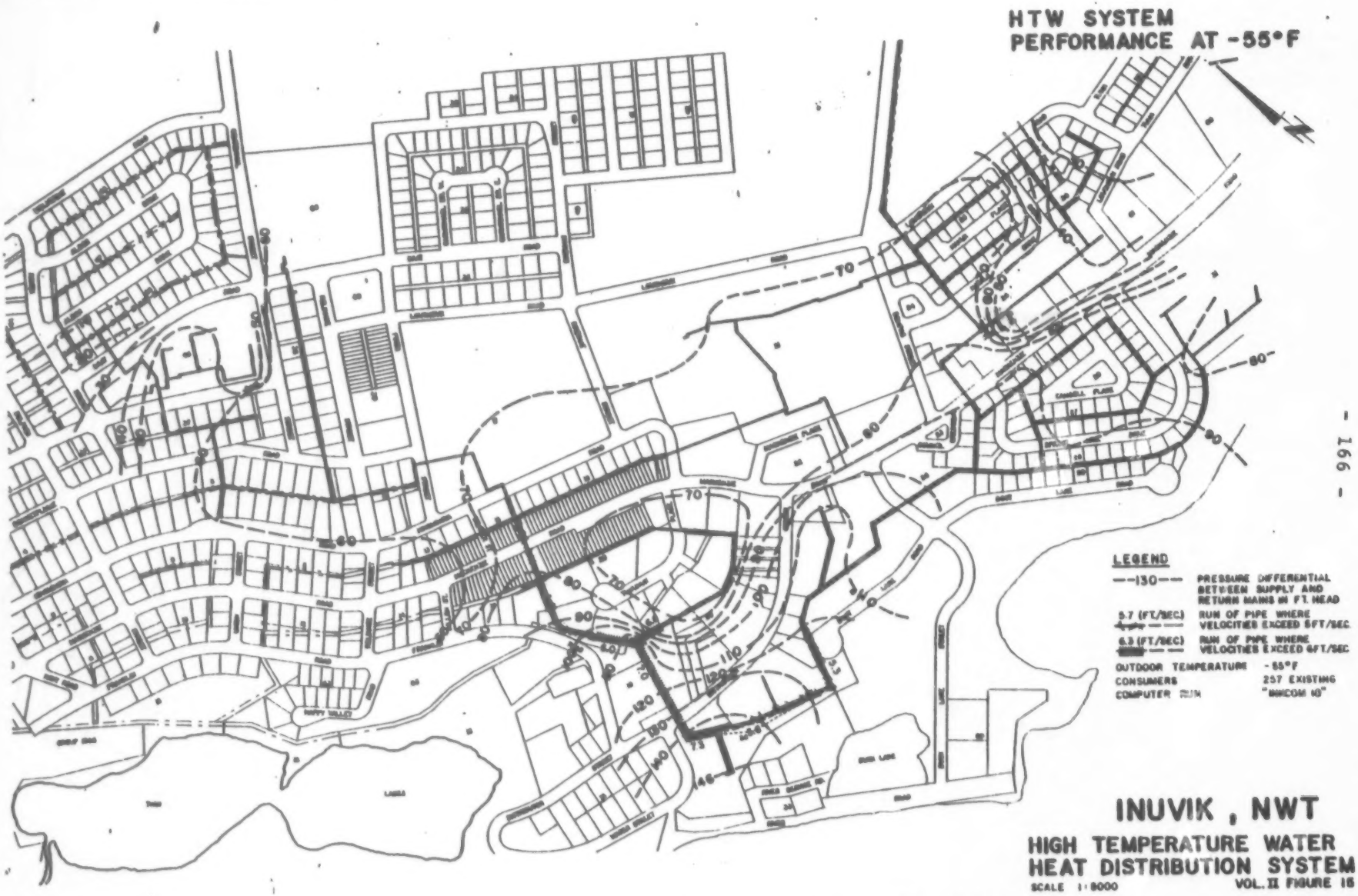
Trial Loads

Computer runs were made at outdoor temperatures of -40°F and -55°F, with existing consumers and, for each run, one large additional trial load. In some instances, trial loads were placed on hypothetical new runs of utilidor. In all cases, unlimited boiler capacity was provided, so that the trial would in fact test distribution system hydraulic capacity. Trial loads and hypothetical utilidor runs include

- a load of 1734 MBH, equivalent to 17 houses, on a short new loop of utilidor joining Block 30 to the Hidden Lake utilidor, the potential location of a future block of houses,


HTW SYSTEM
PERFORMANCE AT +10°F
LEGEND
—130— PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT HEAD
5.7 (FT/SEC.) RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC
6.3 (FT/SEC.) RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC
OUTDOOR TEMPERATURE : +10° F
CONSUMERS : 257 EXISTING
COMPUTER RUN : "INKCOM 7"
INUVIK , NWT
HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM
SCALE 1:8000
VOL. II FIGURE 13

HTW SYSTEM
PERFORMANCE AT -40°F
LEGEND
-130- PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT HEAD
6.7 (FT/SEC.) RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC
6.3 (FT/SEC.) RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC
OUTDOOR TEMPERATURE : -40°F
CONSUMERS : 257 EXISTING
COMPUTER RUN : "INKCON 6"
INUVIK , NWT
HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM
SCALE 1:8000
VOL. II FIGURE 14


HTW SYSTEM
PERFORMANCE AT -55°F
LEGEND
—130— PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT. HEAD
5.7 (FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 5FT/SEC
6.3 (FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC
OUTDOOR TEMPERATURE -55°F
CONSUMERS 257 EXISTING
COMPUTER RUN "INNCOM 10"
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1:8000
VOL. II FIGURE 18

- a new load of 5000 MBH, in the same location,

- a load of 8300 MBH, equivalent to all the row housing presently occupying Blocks 45, 46, and 47, on a new run of utilidor running between Inuit and Loucheux roads, centered on Block 32,

- a load of 12,000 MBH in the downtown area, Block 13 (about three times the load of the existing Bay store), and,

- a load of 17,000 MBH, at the same downtown location.

It is emphasized that these loads are quite arbitrary. They were chosen to test the system severely, and determine its response, rather than to model developments actually being contemplated. Responses are described below.

Response to 1734 MBH Load Near Block 30

The system successfully carried the trial 1734 MBH load (equivalent to 17 houses) on a hypothetical new run of utilidor above Loucheux Road and south of Bompas. All consumers had sufficient heat at -55°F. The calculated total system load, including utilidor losses, was 80.2 MMBH, and the flow at the powerhouse was 1690 Igm. The maximum velocity anywhere in the system was 7.4 ft/sec.

The pressure differential in Block 30 improved from 29 ft to 52 ft, apparently due to the additional looping. However, the differential in Block 47 at the far end of the system declined from 7 ft to 3 ft, a very marginal value. Velocity changes throughout were not large.

Pressure differentials and zones of high pressure loss are mapped in Figure 16.

Response to 5000 MBH Load Near Block 30

When the trial load near Block 30 was increased from 1734 to 5000 MBH, pressure differentials at the same (south) end of the system remained adequate. The pressure differential in Block 30 was 22 feet as compared to 29 feet with no additional load.

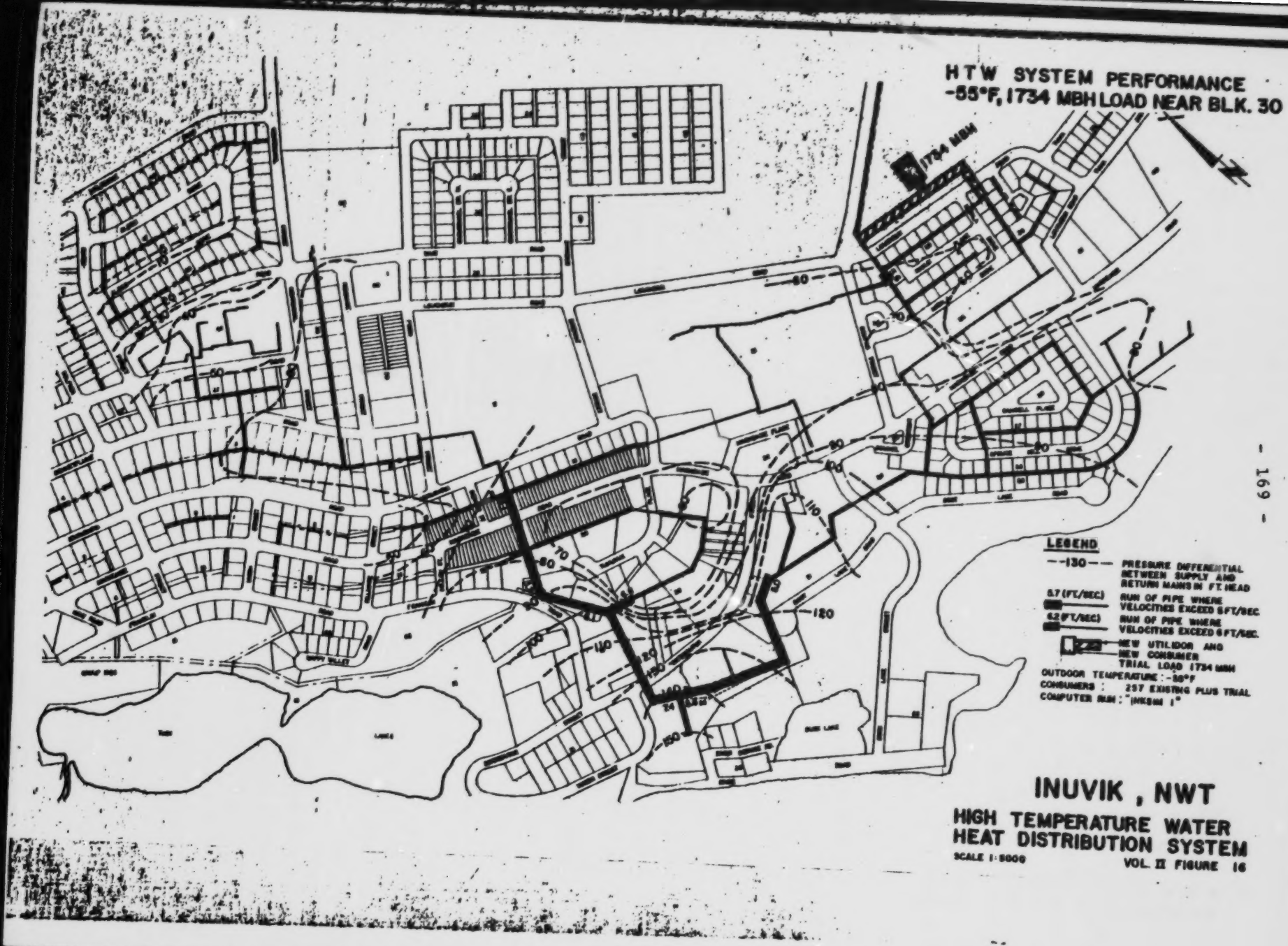
The north end of the system did not fare as well. The increased demand in the south branch drew pressure differentials in Block 47 down to levels as low as 1.6 ft. A number of consumers in Blocks 46 and 47 were short of heat. A consumer at the end of the Block 13 utilidor was also short, in spite of a pressure differential in excess of 40 feet (17 psi).

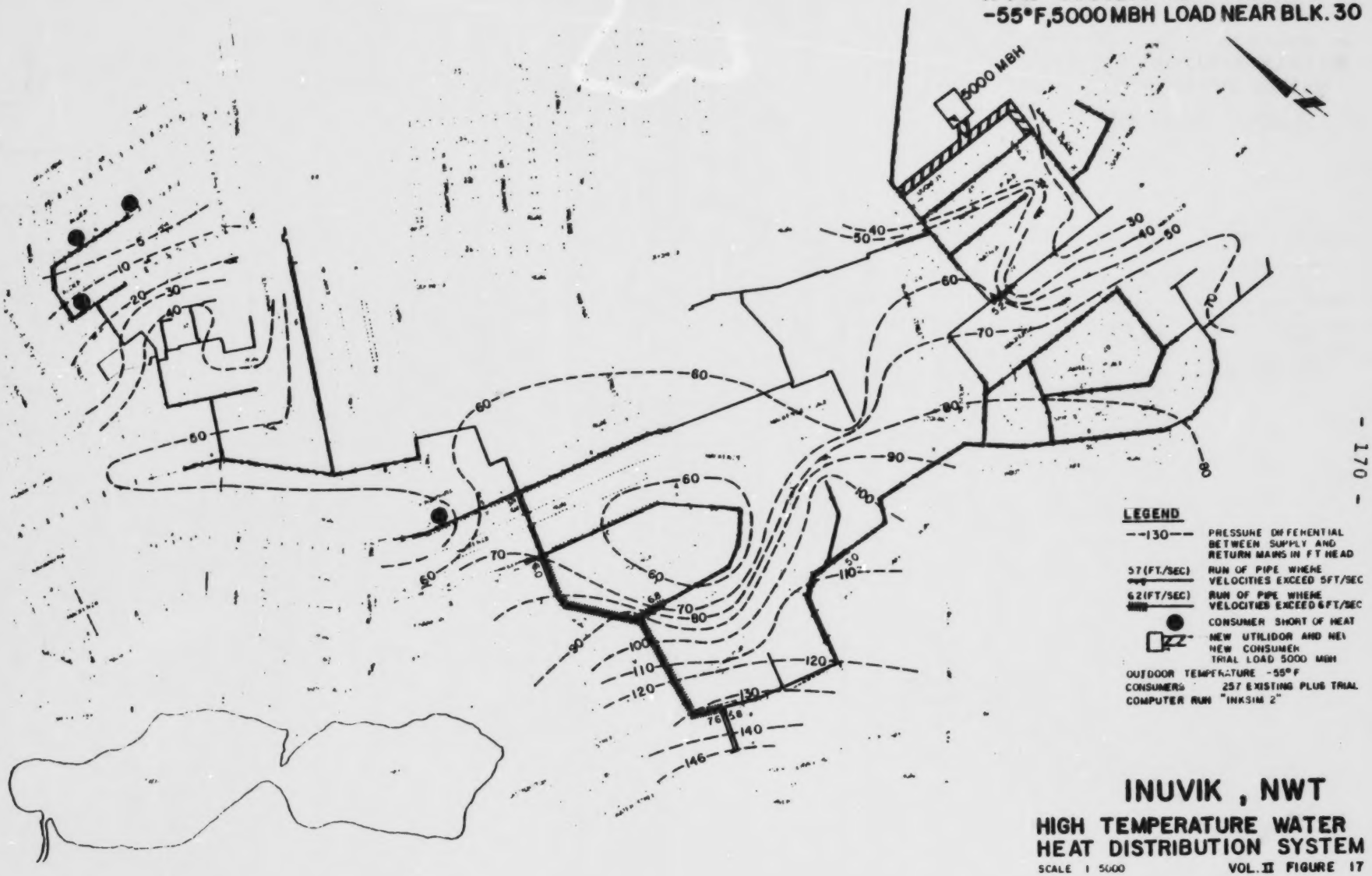
The calculated total system load and flow were 83.7 MMBH and 1740 igm, respectively. The maximum velocity was 8.2 ft/sec. Pressure differentials, zones of high velocity and high pressure loss, and consumers in difficulty are mapped in Figure 17.

Response to 8300 MBH Load Near Block 32

In this trial, a hypothetical run of utilidor was added between Block 36 and Block 21, providing a new connection between the north and south main branches of the system. The load in the new run was 8300 MBH, equivalent to the Federal row housing complex now occupying Block 45 and portions of Blocks 46 and 47.

The new connection did not appear to upset the balance between main branches, however, the system was not able to deal with the new load. Most consumers in Blocks 46 and 47 were short of heat, and similar


HTW SYSTEM PERFORMANCE
-55°F, 1734 MBH LOAD NEAR BLK. 30
1734 MBH
LEGEND
130 PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT. HEAD
5.7 (FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 5 FT/SEC.
6.2 (FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 6 FT/SEC.
NEW UTILIDOR AND NEW CONSUMER TRIAL LOAD 1734 MBH
OUTDOOR TEMPERATURE : -55°F
CONSUMERS : 257 EXISTING PLUS TRIAL
COMPUTER RUN : "INKSIM 1"
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. II FIGURE 16


HTW SYSTEM PERFORMANCE
-55°F,5000 MBH LOAD NEAR BLK. 30
5000 MBH
LEGEND
—130— PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT HEAD
57(FT./SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 5FT/SEC
62(FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC
CONSUMER SHORT OF HEAT
NEW UTILIDOR AND NEW CONSUMER
TRIAL LOAD 5000 MBH
OUTDOOR TEMPERATURE -55°F
CONSUMERS 257 EXISTING PLUS TRIAL
COMPUTER RUN "INKSIM 2"
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1 5000
VOL. II FIGURE 17

problems occurred in Block 13, Block 28 and Block 30. Blocks 46 and 47, and Block 30, represent the extreme ends of the system. Pressures declined to 1.6 ft in Block 47, and to 15 ft (from 29 ft) in Block 30. Consumers having difficulty in other areas were ones with long utilidettes and small diameter piping, and much of the pressure loss problem was created in their own systems.

The calculated total system load and flow were 86.5 MMBH and 1780 igm, respectively. Maximum velocity was 7.8 ft/sec. Results are mapped in Figure 18.

Response to 12,000 and 17,000 MBH Loads Downtown, Block 13

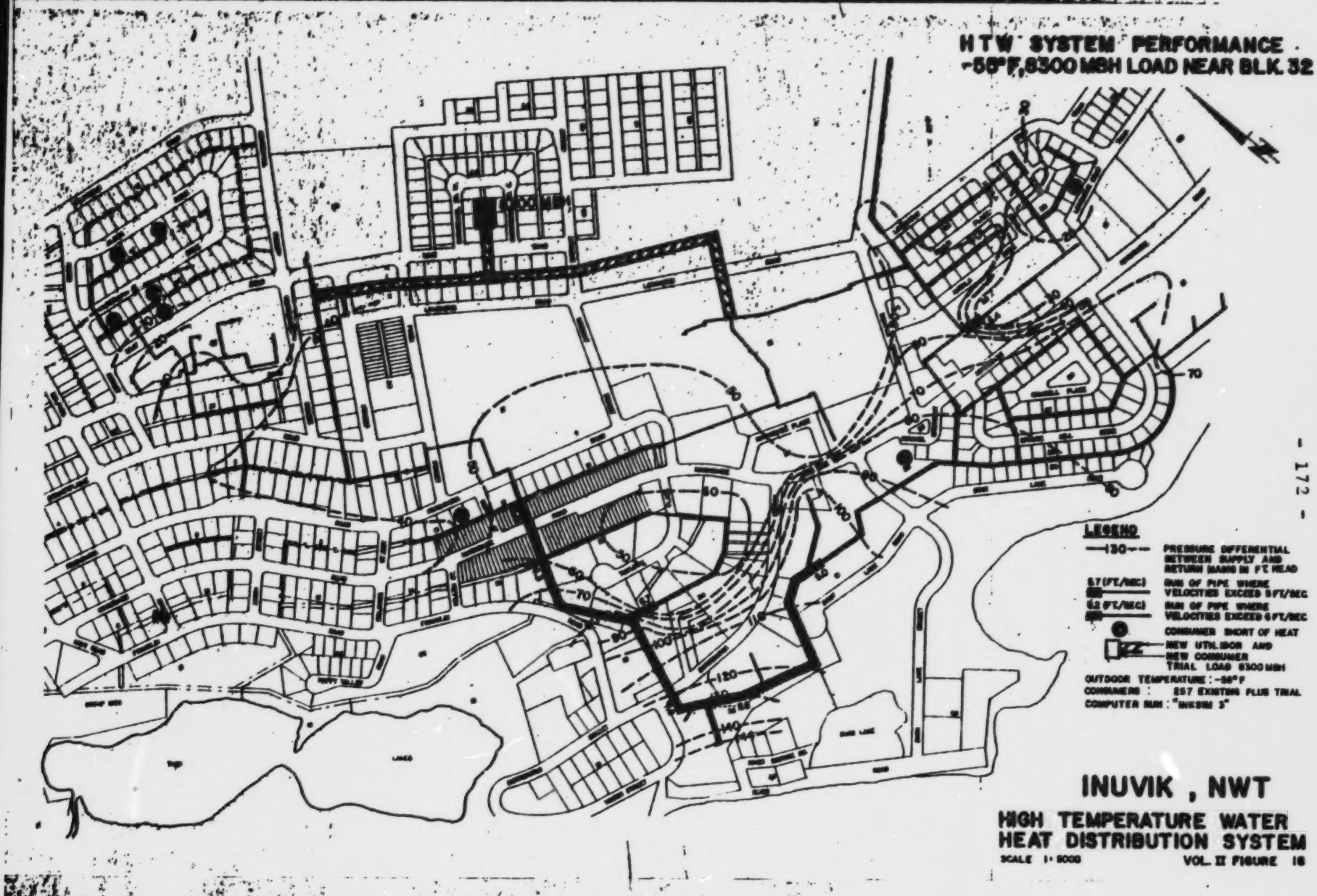
These simulations tested the system's response to a large new consumer located on large diameter mains in the downtown area.

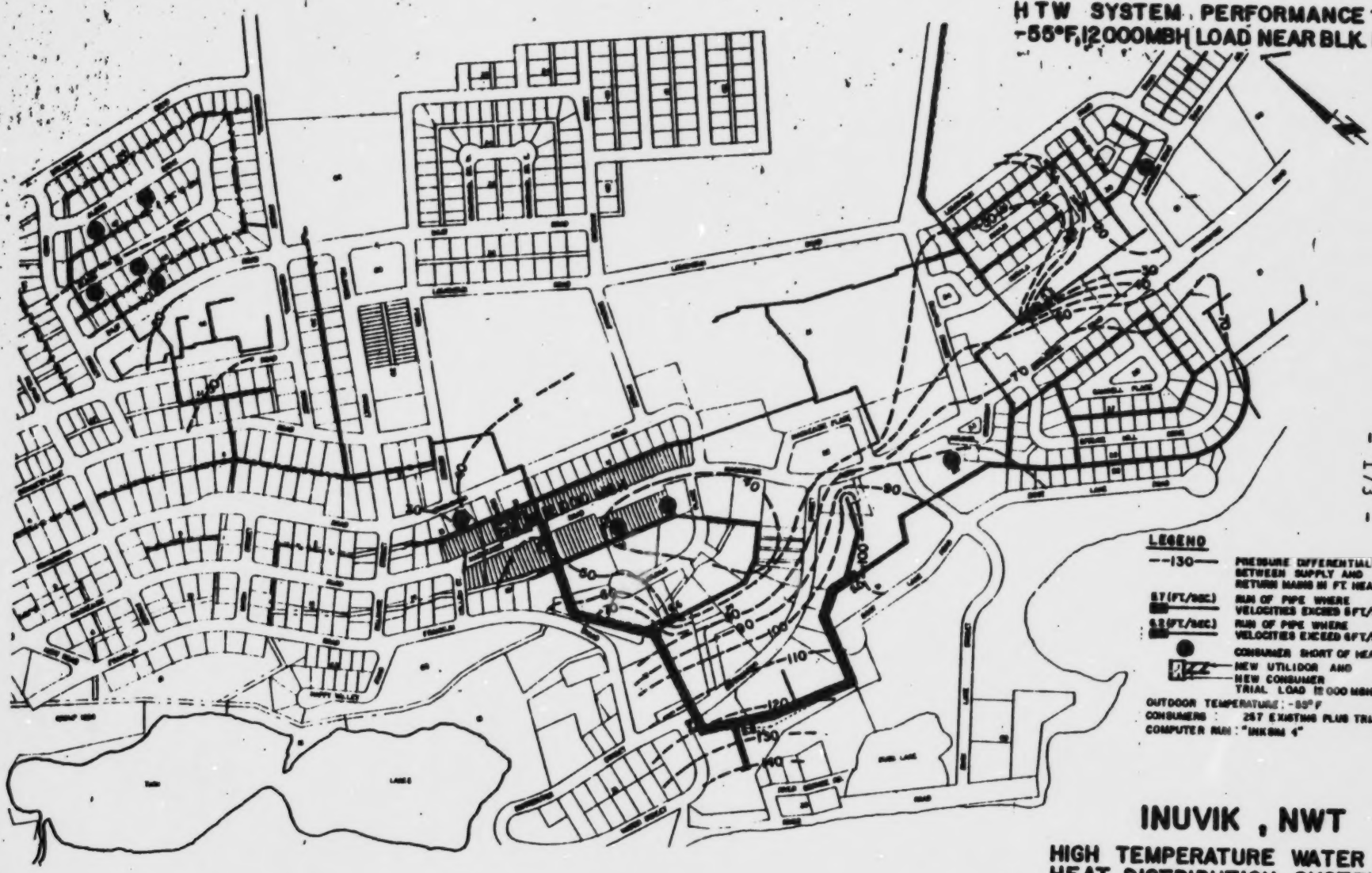
The 17,000 MBH load was actually tried first, and the system was found to be grossly overloaded. Extensive heat shortages developed at both system extremities, and a number of consumers on central sections of the system also were unsatisfied. It was decided to try again, with a smaller but still substantial new load.

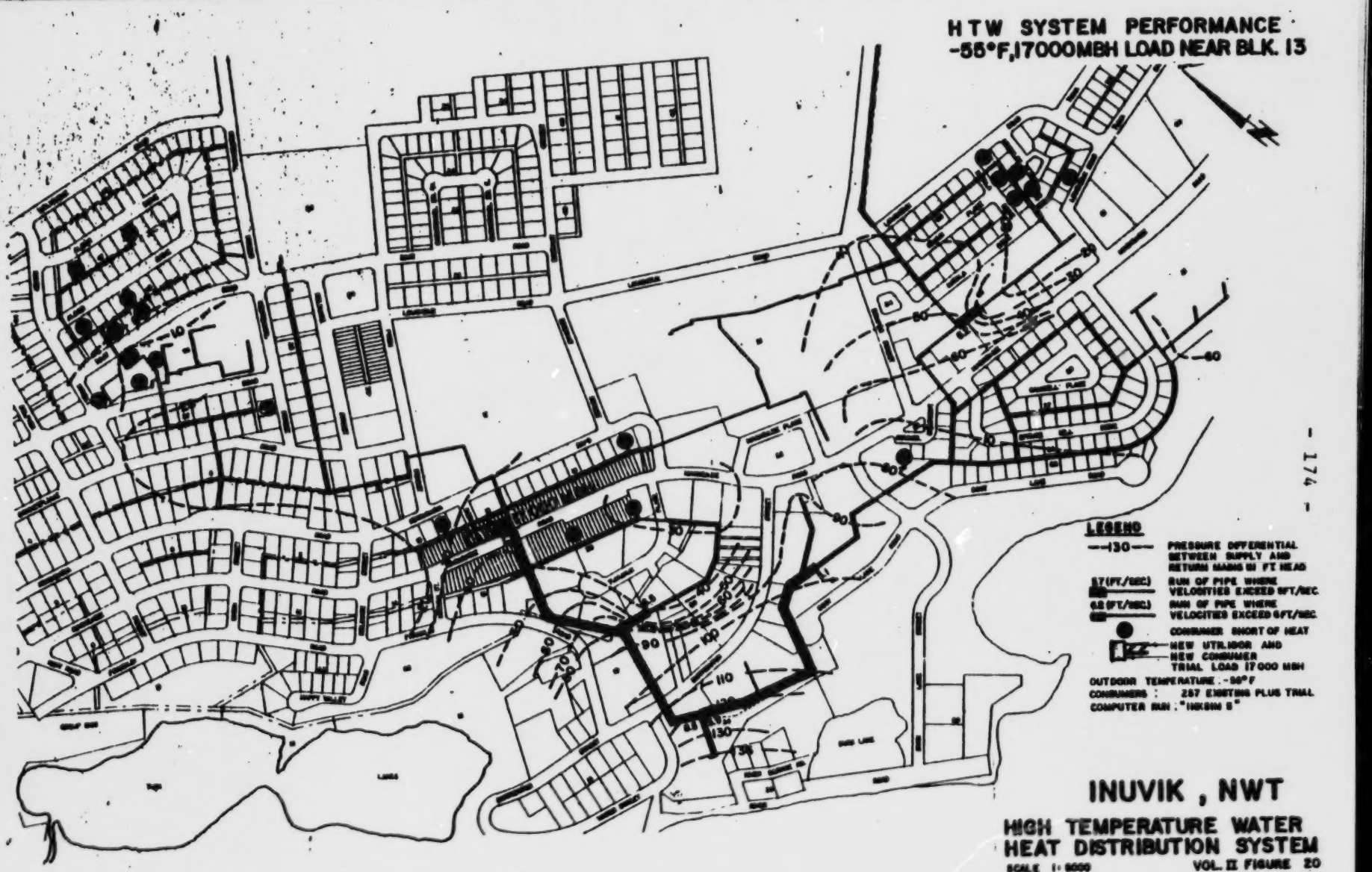
The 12,000 MBH load also overloaded the system, though not by as much. Numbers of consumers at both ends of the system and elsewhere were without enough heat. Residual pressures were less than 5 feet in Block 47, and less than 20 feet in Block 30. Results are mapped in Figure 19 (the 12,000 MBH load) and Figure 20 (17,000 MBH load).

Conclusions

The loads used in the capacity trial simulations were designed to test the system severely, and evidently did so. The tests provided good information about the system's behavior and limits.


HTW SYSTEM PERFORMANCE
-58°F, 8300 MBH LOAD NEAR BLK. 32
LEGEND
—130— PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT HEAD
5.7 (FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 5 FT/SEC
6.2 (FT/SEC) RUN OF PIPE WHERE VELOCITIES EXCEED 6 FT/SEC
CONSUMER SHORT OF HEAT
NEW UTILIDOR AND NEW CONSUMER TRIAL LOAD 8300 MBH
OUTDOOR TEMPERATURE : -58°F
CONSUMERS : 257 EXISTING PLUS TRIAL
COMPUTER RUN : "INKSM 3"
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. II FIGURE 18


HTW SYSTEM PERFORMANCE
-55°F, 12000MBH LOAD NEAR BLK 13
LEGEND
—130— PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT. HEAD
8.7 (FT/SEC.) RUN OF PIPE WHERE VELOCITIES EXCEED 8 FT/SEC.
6.3 (FT/SEC.) RUN OF PIPE WHERE VELOCITIES EXCEED 6 FT/SEC.
CONSUMER SHORT OF HEAT
NEW UTILIDOR AND NEW CONSUMER TRIAL LOAD 12 000 MBH
OUTDOOR TEMPERATURE : -55° F
CONSUMERS : 257 EXISTING PLUS TRIAL
COMPUTER RUN : "INKSM 4"
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. II FIGURE 19


HTW SYSTEM PERFORMANCE
-55°F,17000MBH LOAD NEAR BLK. 13
LEGEND
—130— PRESSURE DIFFERENTIAL BETWEEN SUPPLY AND RETURN MAINS IN FT HEAD
RUN OF PIPE WHERE VELOCITIES EXCEED 9FT/SEC.
RUN OF PIPE WHERE VELOCITIES EXCEED 6FT/SEC.
CONSUMER SHORT OF HEAT
NEW UTILIDOR AND NEW CONSUMER TRIAL LOAD 17000 MBH
OUTDOOR TEMPERATURE : -55°F
CONSUMERS : 257 EXISTING PLUS TRIAL
COMPUTER RUN : "HKBIN 8"
INUVIK , NWT
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM
SCALE 1:5000
VOL. II FIGURE 20

The district heating system performs well at current loads. It now has some reserve capacity, and the amount appears to be ten to twenty percent of current load.

Capacity is not limited by boiler capacity or by the performance limits of the circulation pump. It is limited by the hydraulics of the distribution network.

Naturally, network pressures and flows could be increased to a degree, if needed, by increasing pumping head at high flows. Head could be increased either by bringing a second existing pump on line, or by switching over to an even higher head, high capacity pump added for that purpose.

The principal source of pressure loss in the distribution network is pipe friction in a small number of fairly short main pipe runs. These seem to have been undersized, possibly inadvertently, or perhaps deliberately for hydraulic balance. Bottlenecks can be seen in the pressure loss maps, Figures 16 to 20, and include

- pipes leaving and entering the powerhouses, 8 inch diameter, 1568 ft long,
- pipes running east from junction 96, Block 19-20, 3 inch diameter, 233 feet long (pipe 2020),
- pipes linking Blocks 45 and 46, 3 inch diameter, 496 ft long (pipe 4504),
- pipes in Block 26 which feed Block 30, 3 inch diameter, 280 ft long (pipe 8206), and
- pipe linking Blocks 46 and 47, 2 1/2 inch diameter, 445 ft long (pipes 8462 and 8471).

If a significant increase in capacity were required in a particular branch of the system, as might be needed to serve some planned new development, then it would be possible (at some cost) to remove the one or two bottlenecks on the route to the area by replacing a few hundred feet of main pipe with a larger size. However, any such operation would have to be based on careful analysis and planning, since a change anywhere in the system affects hydraulics and capacity throughout.

Similarly, the addition of any significant load anywhere on the system affects hydraulics throughout. Estimating the probable effects elsewhere, and in particular in the more vulnerable areas of the system, necessarily involves modelling the complete system with the proposed change incorporated.

As expected, the extremities of the system were found to be the most vulnerable to heat shortage due to hydraulic overload. The north end of the system tends to be affected first, and most, regardless of where the load was placed in the system.

ANALYSIS OF EFFICIENCY

Introduction

The objective of this section is to determine the efficiency of the district heating system. Knowledge of overall efficiency is useful in comparing district heating to other heat supply options, and knowledge of specific components of efficiency loss is useful in evaluating potential improvements.

Efficiency is the proportion of energy in a unit of fuel that is delivered to useful end purposes. Useful purposes exclude the heat requirements of the heating system itself. The concept of efficiency is straightforward,

but its application to a complex system is not. Inuvik's HTW system comprises three main sub-systems, considering the boiler plants and associated equipment, the distribution mains, and consumers. Furthermore, HTW facilities in the powerplants are interdependant with the Inuvik-Tuk electrical generation facilities. Besides sharing fuel storage and fuel supply facilities, there are actual flows of energy between the heat and electric systems at several points. Therefore, a calculation of the efficiency of the district heating system must be based on some stated definition of its boundaries. It is also necessary to convert the electrical energy used by the HTW system to its true heat equivalent of fuel, considering generation efficiency.

For the purposes of this section, the district heating system is considered to include boilers, circulation pumps, main pipes and consumers' connection pipes. Heat used to warm fuel and air consumed by boilers is charged against district heating, as is electrical energy used to run boiler fans and distribution pumps. Heat used to warm fuel and air consumed by electrical generators is considered to be usefully delivered to a "consumer", outside the HTW system. Similarly, heat used to heat the powerhouse, including heat lost from boiler jackets and pipes, which performs the same useful function, is also considered to be delivered to a "consumer", even though the powerhouse exists in part to house the boilers. Outright losses include heat discharged from the boiler flue, and heat that escapes from utilidor main pipes and consumers' connection pipes.

Electrical energy consumed by the district heating system has been converted back to unburnt fuel, considering both the thermal equivalent of electrical energy and the net overall efficiency of the power generating system. It is charged to HTW system operation as the thermal equivalent of the fuel used to produce the electricity used. Large electricity users include boiler fans and fuel pumps, and the HTW distribution system circulation pump.

Scope of Investigation

The calculation of the efficiencies of boilers and pumps has been introduced earlier, and is described in more detail in this section. Also described earlier, and used in this analysis, are the hypothetical scheduling of boilers, the ability of the computer program Hydrotherm III to determine heat flows in the utilidor system, and the synthesis of the monthly and annual outdoor temperature profiles which determine the variable portion of HTW system load.

Analysis of Boiler Efficiency

An annual heat balance was calculated for the boiler plant, by the procedure described below. A heat balance, incidentially, is an accounting of the end use (or loss) of all energy put into the facility, either as combustion fuel or as power used to run fan motors, fuel pumps and other electrical components.

1. Manufacturer's data was used to calculate energy inputs (both fuel and power), net output, heat lost through boiler stacks, jacket radiation, and heat consumed in heating boiler fuel and make-up air, throughout the range of loading, for each boiler. Where manufacturer's information was not available for a particular unit, estimates were based on data for similar units. Radiation from piping within the powerhouse was also estimated, and added.

2. Heat flows to consumers and utilidor losses were determined throughout the range of outdoor temperatures, using Hydrotherm III. This analysis yielded the net distribution system load as a function of outdoor temperature.

3. It was decided for convenience to include the HTW circulation pump as part of the boiler plant. Its monthly electrical load was estimated.

4. HTW heat needed to heat the powerhouse was calculated, throughout the range of outdoor temperatures. The amount of heat provided by losses from boiler jackets and indoor HTW piping was deducted from the total. The amount of heat provided by losses from engine jackets, stacks and indoor sections of cooling systems was also calculated, with due regard to engine load scheduling (which is largely not a function of outdoor temperature). This amount was also deducted from building heat load at low temperatures, to be added to the load temperature function just described.

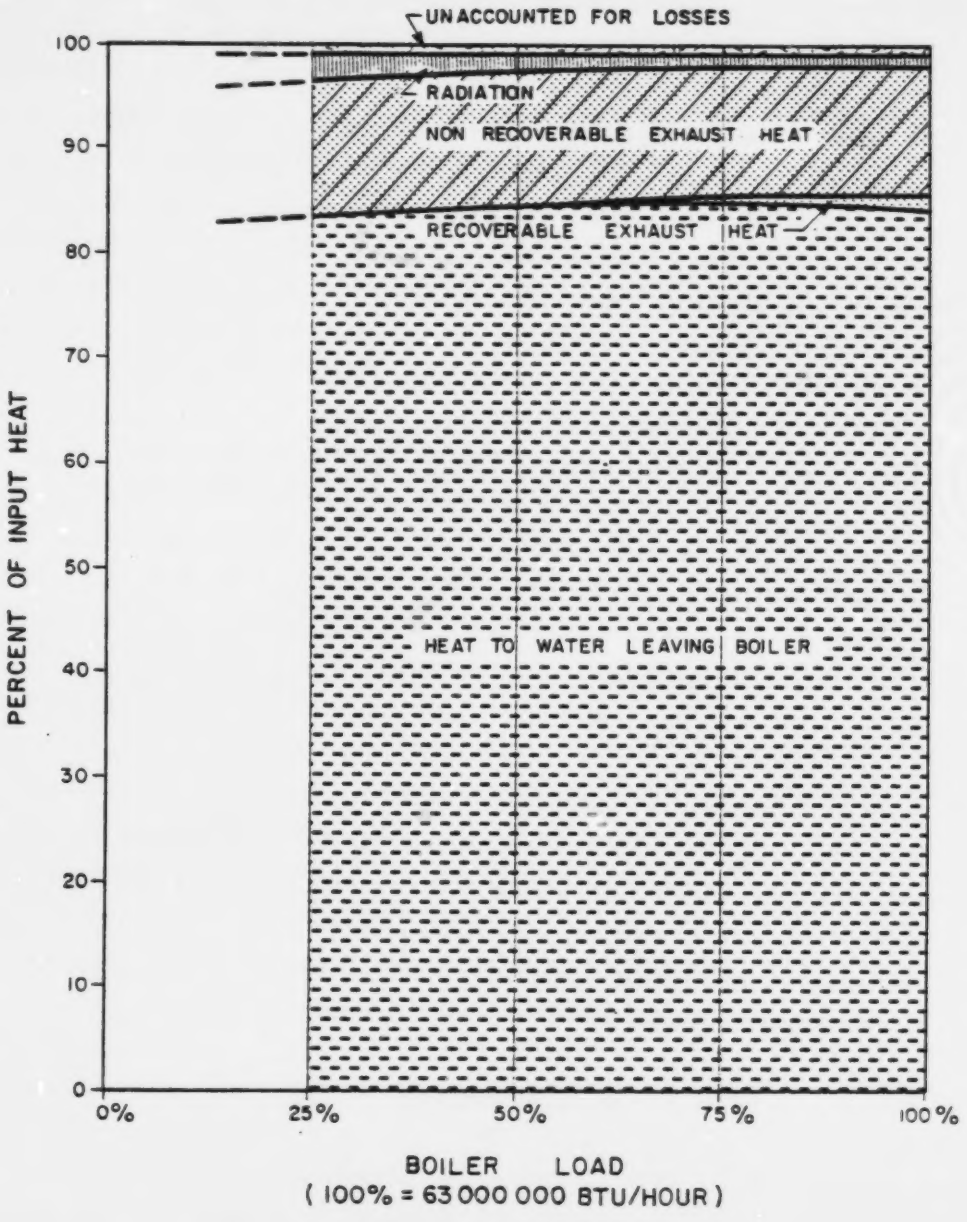
5. HTW heat needed to heat fuel and air for electrical generators was calculated, monthly, using monthly electrical load profiles. (Energy flows created by electrical generation were analysed in detail for the assessment of waste heat recovery options. These analysis are described later).

6. Monthly temperature profiles, the load-temperature function determined as described, the boiler scheduling scheme reported earlier, and the boiler energy flow relationships described were used to calculate net load and total energy flows, for each month. Heat needed to service electrical generation was added, and energy flows reiterated. Pump energy requirements were added.

7. Monthly heat balances were complied to provide an annual heat balance.

The energy balance for a single boiler is shown in Figure 21. The annual heat balance around the boiler plant is shown in Figures 22 and 23.

CLEAVER BROOKS BOILER ENERGY BALANCE

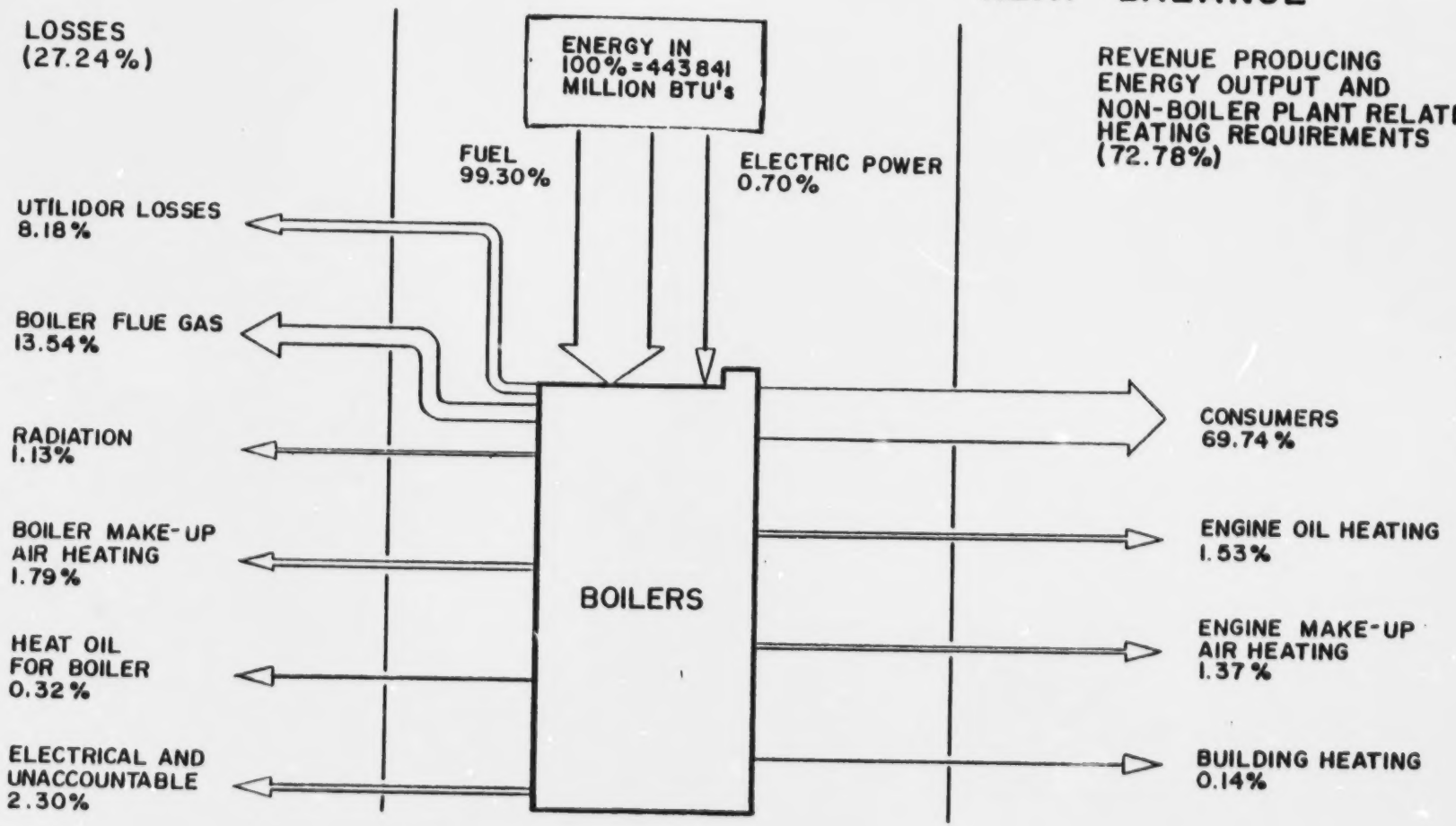


INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 21

BOILER PLANT HEAT BALANCE

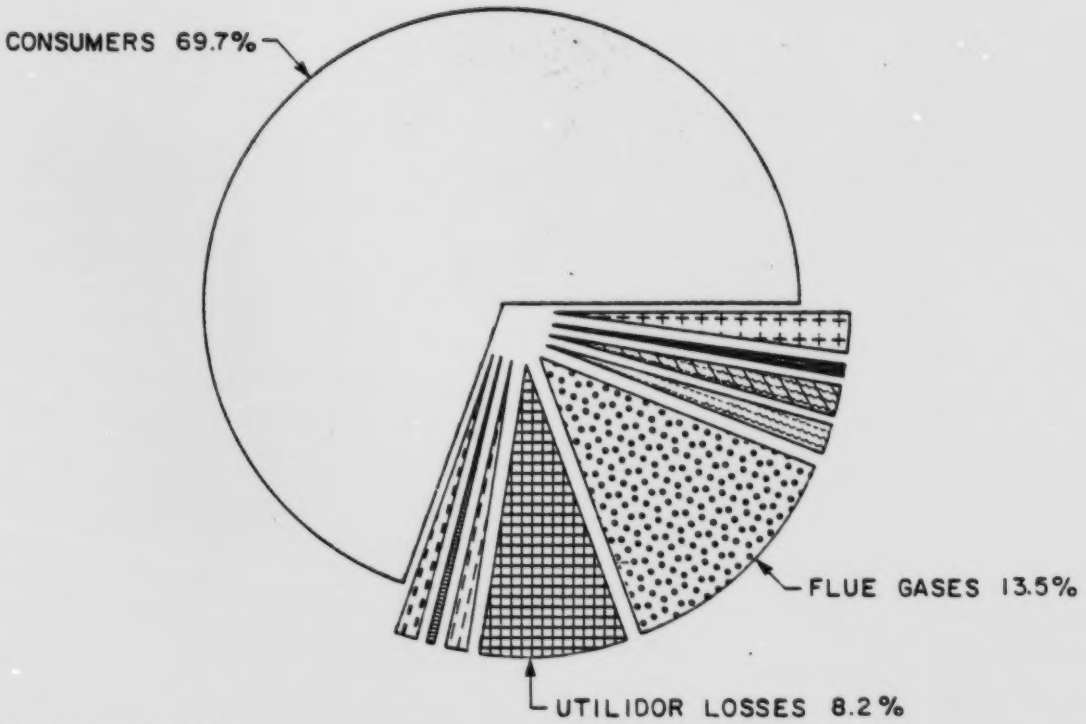


INUVIK, NWT

HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 22

BOILER PLANT HEAT BALANCE



TOTAL LOSSES : 27.2%
100% = 443.8 x 1000 000 000 BTU/YEAR

CONSUMERS
ENGINE OIL PREHEAT
PLANT BUILDING HEAT
ENGINE MAKE-UP AIR
UTILIDOR LOSSES
FLUE GASES
BOILER RADIATION
BOILER MAKE-UP AIR
FUEL OIL PRE-HEAT
POWER & UNACCOUNTABLE

INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 23

It will be seen that of all energy put into the boilers, 77.9 percent reaches the utilidor, and a further 2.9 percent provides a necessary service to the power generators, for a net boiler plant efficiency of 80.8 percent. A further 0.14 percent heats the powerhouse and some of the 1.13 percent which is radiated performs the same useful work, so net efficiency is actually a little higher.

Analysis of Distribution System Efficiency

Of the 443,800 MMBTU put into the boilers annually, an estimated 77.92 percent or 345,800 MMBTU reaches the utilidor system. This figure includes 1410 MMBTU put in by the circulation pump, net after radiation losses.

Of this amount, 89.5 percent or 309,500 MMBTU is delivered annually to customers outside NCPC's plant.

Calculations indicate that utilidor interiors remain at temperatures far above outdoor temperatures throughout, and this has been confirmed by observation. The rate of heat loss from utilidors does not vary much over the year, and at summertime temperatures may account for as much as a third of the heat reaching the distribution system. Table 11 shows the magnitude of utilidor heat losses and their relative importance.

TABLE 11

UTILIDOR HEAT LOSSES

Temperature °F	Input to Udor MBH	Udor Loss MBH	Percent
70	10,209	3,624	35.5
10	43,271	3,990	9.2
-40	70,673	4,273	6.0
Annual	345,800 MMBTU	36,300 MMBTU	10.5

Obviously, increasing system load by adding new consumers would diminish the relative importance of utilidor losses and increase calculated efficiency. It would not, however, reduce the total amount of heat lost, or its cost.

Conclusions

The net annual efficiencies of the boiler plant, the utilidor system and the district heating system as a whole are listed in Table 12.

TABLE 12

HTW SYSTEM ANNUAL EFFICIENCY

Component	Input MMBTU	Net Output MMBTU	Efficiency %
Plant	443,800	359,300	81.0
Distribution System	345,800	309,500	89.5
Total District Heat	443,800	323,000	72.8

Notes

(a) Heat delivered to power generators and heat known to be used for powerhouse heating is classified as usefully delivered to a consumer, not as lost.

Detailed efficiency data generated in this section of the work were used in subsequent analyses.

METHODS OF INCREASING EFFICIENCY

Introduction

The net annual efficiency of the district heating system is now 72.8 percent. Of the 30.3 percent of input energy which does not reach consumers, 44.7 percent (13.5 percent of total) is lost through boiler stacks and 27.0 percent (8.2 percent of total) through distribution system losses.

The possibility of recovering heat from boiler and engine stacks is dealt with later in the report.

This section deals with less complex improvements intended to reduce losses from the other significant source, the distribution system. These do not involve great changes to the system, and two of the improvements could be undertaken at very modest cost. The improvements considered are

- to reduce distribution system heat losses by insulating the HTW piping in vaults,

- to further reduce distribution system losses by increasing the insulation on all pipes; or to achieve the same end by increasing the insulation of the utilidor, and

- to reduce boiler plant and distribution system heat losses by varying HTW supply temperature in response to load.

It was suggested in Volume I of this report that some "Type 2" consumers convert to "Type I" for reasons of safety. Conversion to a better controlled heating system would have the additional benefit of improving utilization of both heat and hydraulic capacity, to a minor extent.

Scope of Investigation

System performance data, temperature profiles and published cost estimating information were all used in the analyses described below.

Insulate Vault Piping

HTW piping in utilidors is all insulated, and by and large the insulation in utilidor runs is in good condition.

A great deal more construction, operations and maintenance activity takes place in the vaults, and such insulation as may originally have been installed on HTW piping in vaults has now largely disappeared.

The total amount of heat lost each year from utilidors is estimated to be 36,300 MMBTU, valued at $555,390 at NCPC's 1984 non-government charge rate of $15.30. It is estimated that insulating vault piping would reduce the loss by 4860 MMBTU. The annual saving in fuel cost only, without overhead, would be $51,800.

The cost of insulation is estimated to be $23,500, installed.

The payback period was not computed.

It would also be cost effective to replace insulation on HTW piping, in the small number of utilidor runs (near the powerhouse) where it has deteriorated.

Increase pipe Insulation

The total length of main utilidor is 28,200 ft, and utilidettes increase this figure by about 30 percent. Therefore, the total length of pipe over which heat loss occurs is in the neighborhood of 75,000 ft.

Neglecting the large differences in pipe diameter and circumference, heat loss from the insulated pipe averages about 462 MBTU/ft-year (foot of pipe), valued at $4.90/ft-year (fuel cost only, no overheads). If increasing the insulation on pipes would save, say, half this amount, the present value of savings over 20 years at 8 percent would be $24.15/ft of pipe.

Since the cost of increasing insulation would be about $60/ft of utilidor, or $30/ft of pipe, the concept is not cost effective, and is dropped.

Increase Utilidor Insulation

Increasing the insulation around the utilidor perimeter would increase the interior temperature, and thereby decrease the rate of heat loss from HTW lines.

Unfortunately, the cost of doing this would be greater than the cost of re-insulating HTW pipes, and the gains considerably less. This proposal is also discarded.

Schedule Boiler Output Temperature

Currently, high temperature water is supplied to the utilidor system at 350°F, throughout the year. System modelling indicates that this temperature is appropriate during very cold weather, but unnecessarily high at other times.

Hydrotherm runs have shown that the system would continue to serve its building heat customers equally well with a supply temperature of 350°F for outdoor temperatures below -40°F, of 250°F for temperatures above 70°F, and linear interpolation between these extremes.

This temperature schedule is shown in Figure 24. Also shown is the frequency of occurrence, in the data year, of each 5°F temperature increment, and the heat saving in each increment that could be achieved by supply temperature scheduling.

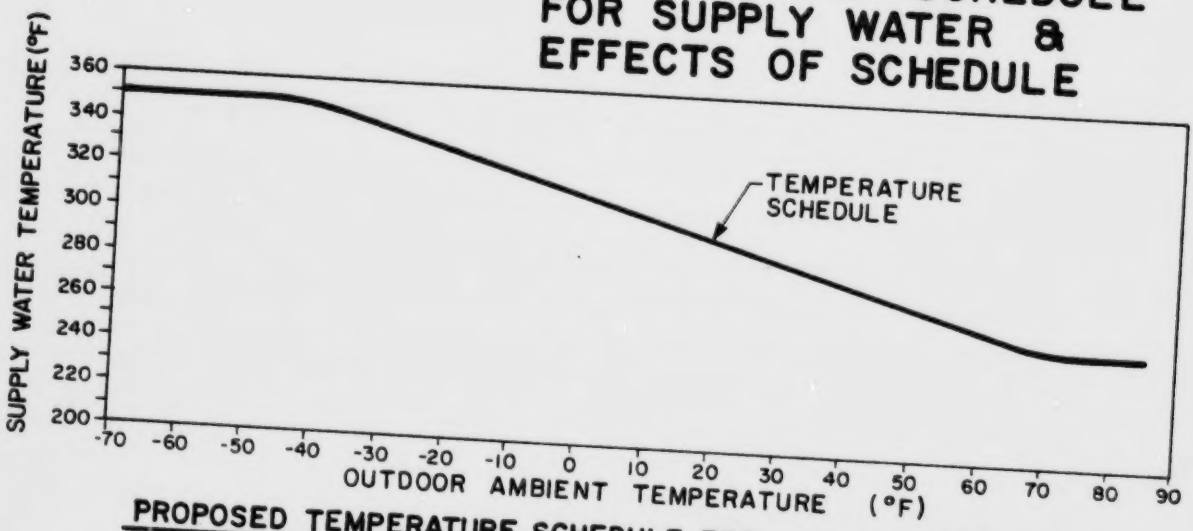
The saving at 70°F would be nearly 1000 BTUH. The annual saving would be 3730 MMBTU. The value of the saving, at fuel cost without overheads, would be $39,700.

It is thought that boiler output temperature scheduling could be arranged with little capital cost, since it could be done through alterations in boiler controls, monitors and alarms.

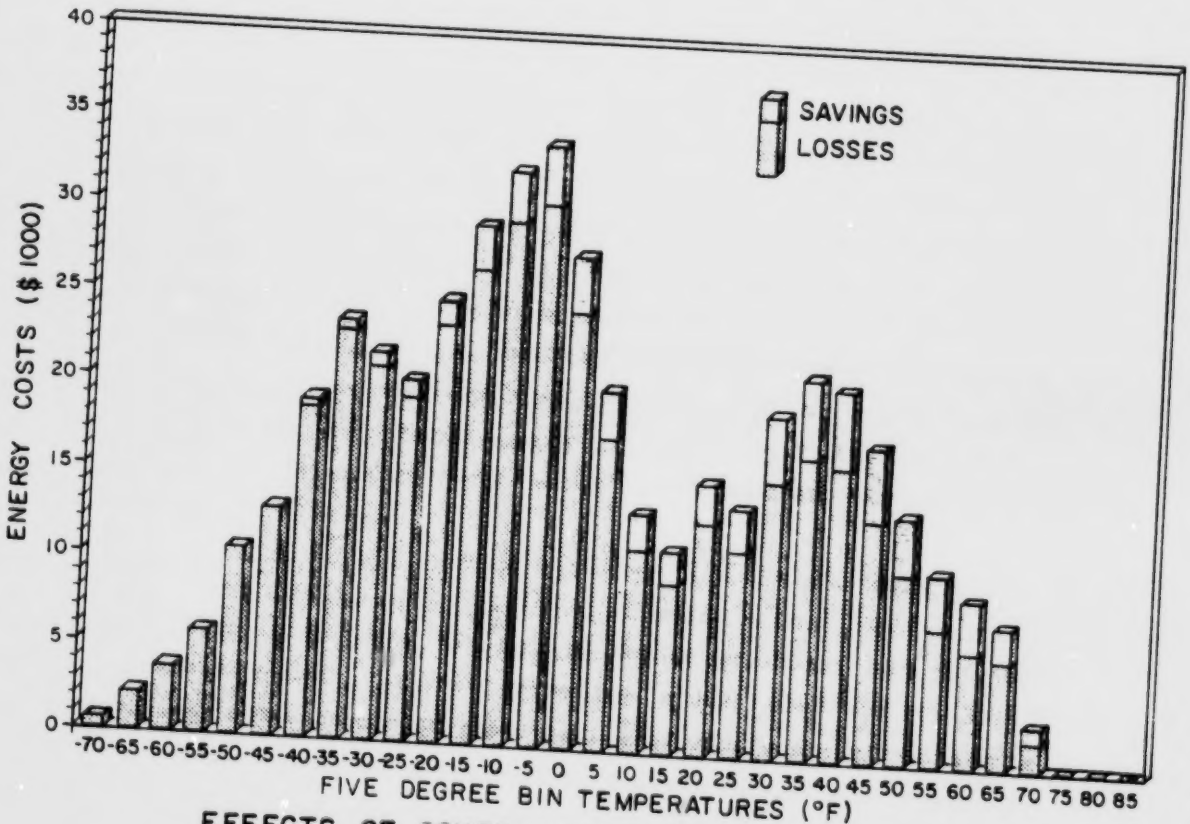
While scheduling looks attractive and worth exploring, potential side effects are not well known. It appears that building heating needs would be satisfied, but the rate of reheating domestic hot water would decline somewhat. There is some possibility that this might inconvenience consumers who draw heavily on their hot water systems.

A second and potentially more important consideration is the possible effect of reduced or fluctuating temperatures on the distribution system's

TEMPERATURE SCHEDULE FOR SUPPLY WATER & EFFECTS OF SCHEDULE



PROPOSED TEMPERATURE SCHEDULE FOR UTILIDOR SUPPLY WATER



EFFECTS OF SCHEDULING SUPPLY TEMPERATURE

INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 24

many expansion joints, especially those apparently restricted in traverse. This would have to be considered carefully, and monitored if a scheduling scheme were adopted. Finally, it has not been determined if a changing output temperature would have any ill effects on the boiler itself.

Conclusions

The analysis indicates that utilidor heat losses could be reduced by 12 to 14 percent by insulating piping in vaults. The cost of the work has been estimated to be $23,500. The annual saving is estimated to be $51,000. This measure is recommended.

Scheduling of boiler output temperature as a function of outdoor temperature potentially could reduce utilidor heat losses by a further 10 percent. The cost of the work would not be large, and the annual saving is estimated to be $39,700. It is not known to what extent scheduling might affect the reheating rate of domestic hot water heaters and, of more consequence, the service lives of expansion joints and boilers. Scheduling is recommended, on a trial basis. If it is adopted, the output temperature scheduling range should be kept small, initially. It would be expanded toward the full suggested 100°F (350°F to 250°F) gradually over a period of months, and effects monitored.

EFFECT OF HEAT CONSERVATION

Introduction

Many of the buildings served by the HTW heat distribution system were built in the late 1950's and early 1960's. Energy costs have risen significantly since that time, and there have been concurrent advances in methods of sealing and insulating wood frame buildings. Double and triple

glazed sealed window units, polyethylene film vapour barrier, improved spun glass insulation, styrene foam board insulation, insulated metal and vinyl siding, and a wide range of caulking on sealing materials with greatly improved adhesive and weathering characteristics have all become widely available only in the last decade or two. In addition, it has now become common to make exterior walls thicker than dictated by structural requirements, to provide additional space for insulation, and to install substantially greater thicknesses of insulation in the entire thermal envelope.

Energy losses in older buildings, constructed to less rigorous standards, can usually be reduced by retrofitting energy conserving features. The gains may be substantial, but capital cost and the expected useful life of the building must also be considered carefully. Some measures, such as sealing cracks and holes to reduce infiltration of cold air, and increasing the insulation in accessible ceiling spaces, usually are worthwhile. Other possible changes, such as replacing window units or increasing the insulation in (or on) walls, entail substantial demolition and reconstruction, and may not be cost effective.

Reduction of energy losses from consumer buildings would reduce the HTW system's fuel requirements, and so would achieve an overall saving in system operating cost. At the same time the unit cost of energy would rise, since the total amount of energy conveyed would decline, but capital costs and most operation costs (aside from fuel cost),* and system losses, would remain the same.

*The cost of HTW heat is apportioned approximately as follows: fuel, 68%; electricity used by boilers and pumps, 4%; overheads, 28%.

The objectives of this section are

- to assess the potential reduction in consumers' energy demands that might result from retrofit measures which would appear to be cost effective,

- to assess the effect of the resulting reduction in energy demands on the operation and economics of the HTW system.

Scope of Investigation

An analysis was made of two conceptual buildings considered to be of "typical" early 1960's construction, one a ten unit multifamily residential building, and the other a 20 room hotel having a restaurant and tavern. Heating loads were calculated using Inuvik's long term average temperature profile. A list of potential retrofit measures was drawn up. Capital costs and energy savings were estimated. The cost effectiveness of different measures was assessed by both present value and payback period methods.

Finally, the overall reduction in energy needs that would accrue to implementation of cost effective measures was estimated, and the potential effect on the HTW system's economics assessed.

Description of Conceptual Buildings

The conceptual residential building comprises ten 1200 square foot (total area), two storey family units. If is of wood frame construction, on piles, and has a 3 foot high mechanical crawl space below, and cold attic above. The exterior finish is wood siding, and the interior drywall. Windows are double pane clear glass. Insulation is R12 in the walls and below the crawl space, and R20 in the ceiling. The heating system is hot

water, baseboard radiation. The mechanical crawl space is heated only to 50°F.

The conceptual commercial building is a two storey hotel, 5000 square feet per floor. It has 20 guest rooms, a tavern, restaurant, lobby, kitchen, mechanical space and some storage. It is also of wood frame construction, with a 3 foot mechanical crawl space below, a flat roof above, wood exterior siding and drywall interior finish. Windows are double pane clear glass. Insulation is R12 in the walls and below the crawl space, and R10 in the roof. The heating system is hot water, baseboard radiation. A forced ventilation system is provided: 5000 cfm. The mechanical crawl space is heated only to 50°F.

Upgrading of Conceptual Buildings

Potential improvements considered are:

1. Reduction of air infiltration from 1.5 to 0.75 air changes per hour, by improved caulking and weatherstripping.*

2. Reduction of heat loss through exterior walls, by addition of two inches of rigid board insulation on the exterior. Work would include removal of existing siding, application of siding straps, extension of window and door frames, application of insulation, and application of new vinyl siding.

3. Reduction of heat loss through the ceiling of the residential building, by addition of cellufibre insulation in the ceiling space to bring total insulation value from R20 to R40.

*It has been pointed out that infiltration may be much higher than 1.5 air changes per hour. If so, then the cost effectiveness of caulking and weatherstripping will be even greater than is indicated in the report sections immediately following.

4. Reduction of heat loss through the roof of the hotel, by addition of two inches of styrofoam board insulation. Work would involve removal of the existing built up roofing, repair of flashings, application of board insulation, and replacement of roofing.

5. Reduction of heat loss through windows, by replacement with triple pane sealed units.

Analysis of Cost Effectiveness of Retrofit Measures

Annual heat losses from building elements before and after retrofit measures were calculated by standard engineering methods (ASHRAE), for an annual heat load of 19,635°F-days below 70°F. Heat saved was valued at $15.30 per million BTU's, NCPC's 1984 price for HTW heat. The present value of savings was computed at a discount rate of 8 per cent over 20 years. Construction costs were estimated using 1984 rates. Results for both conceptual buildings are shown in Table 13.

TABLE 13

COST EFFECTIVENESS OF HEAT CONSERVATION

MULTIFAMILY BUILDING

Retrofit	Cost	Heat Saving		Effective?	Payback Years	
	$	$/yr	$PV		8%	0%
Sealing	2,000	4,437	43,560	Yes	1	1
Wall Insulation	58,000	1,197	11,752	No	-	48
Ceiling Insulation	9,000	952	9,347	Maybe	19	9
Triple Windows	52,000	3,353	32,917	No	-	16

HOTEL

Retrofit	Cost	Heat Saving		Effective?	Payback Years	
	$	$/yr	$PV		8%	0%
Sealing	1,200	3,060	30,043	Yes	1	1
Wall Insulation	42,000	607	5,960	No	-	69
Roof Insulation	24,000	1,226	12,037	No	-	20
Triple Windows	34,000	1,675	16,445	No	-	20

Notes

(a) $PV is present value of savings accumulated over 20 years at a discount rate of 8 percent. The discounted payback period is calculated using the same discount rate. The simple payback period is calculated using a discount rate of 0%.

(b) The savings attributed to sealing and weatherstripping are based on reduction of infiltration from 1.5 to 0.75 air changes per hour. Savings would be greater if infiltration rates are much higher, and still reducable by sealing measures.

Discussion

It will be seen that sealing and weatherstripping are certain to be cost effective in buildings in need of that sort of attention. Savings may not be as dramatic as indicated, however, since the discomfort that would be caused by serious air leaks during Inuvik's extended winters probably result in greater than average attention to building maintenance.

Adding insulation in accessible ceiling spaces may also be cost effective. The use of a lower discount rate would increase the attractiveness of this (and any) measure. For instance, the payback period at 4 percent would be 12 years.

Major and costly renovation projects, such as adding insulation to wall exteriors or under roofing membranes, and replacing windows, are unlikely to repay themselves unless energy costs again rise dramatically in comparison to the economy in general.

Heat conservation measures would reduce consumer loads on the district heating system. The percentage load reduction that would result from implementation of cost effective measures, only, in the case of each of the two conceptual buildings, is shown in Table 14.

TABLE 14

POTENTIAL EFFECT OF HEAT CONSERVATION ON SYSTEM LOAD

Building	Heat Losses MMBTU/yr				Saving	Pcnt
-Retrofit	Conduct	Infilt	Vent	Total	MMBTU/Yr	
Multifamily	990	580	0	1,570		
- sealing					290	18
- ceiling insulation					62	4
Hotel	690	400	3,330	4,420		
- sealing					200	5

Notes:

(a) Pcnt is percent saving

As discussed earlier, 47 percent of the total heat load comes from multifamily housing units, comparable to the conceptual multifamily building. The proportion that comes from highly ventilated commercial and institutional buildings, such as the conceptual hotel, is in the range of

25 to 30 percent. Therefore, it is unlikely that cost effective measures would ever produce an overall heat reduction as high as 20 percent, even if very widely applied. A more realistic upper limit might be in the range of 10 percent.

About 73 percent of the 1984 HTW heat cost of $15.30/MMBTU is for fuel, including the fuel used to generate the small amount of electricity needed by the HTW system. Various overheads, generally fixed, account for 27 percent of the cost. Therefore, a 10 percent reduction in system loading, unreplaced, would result in an energy cost increase in the order of 2.5%. From a base of $15.30/BTU, the price would have to rise to about $15.70. Therefore, the effect that the consumer body would be expected to feel, following a 10 percent reduction in overall heat demand, would be a 7.5 percent reduction in overall heat cost.

Conclusions

Costly and extensive building energy conservation retrofit projects are unlikely to be cost effective. However, sealing and weatherstripping of buildings in need of that kind of attention is certain to be cost effective, and may have a payback period of as little as a single winter. Adding insulation in accessible ceiling spaces is also likely to be cost effective.

Cost effective retrofit measures, even if widely applied, would be unlikely to reduce total system heat load by more than 10 percent. A load reduction of this magnitude would have little or no effect in the operation of the HTW system, but could increase HTW energy production costs by around 2.5 percent. Such a cost increase might be avoided if the lost load could be replaced with little capital outlay, for example, by encouraging consumers who have disconnected to resume use of HTW heat, or by gaining new customers among buildings already located beside HTW

utilidors. If the unit cost did increase by 2.5 percent, the consumer body would still achieve a net 7.5 percent reduction in heat cost.

OPTION OF ABANDONING DISTRICT HEATING

Introduction

The HTHW system supplies heat to buildings and the water system at a certain cost. It is possible that the cost of HTW might at some time in the future be less than it is now, if the economics of heat and power generation come to be improved by recovery of waste heat or other changes.

On the other hand, it is also possible that it might be more cost effective to abandon district heating and provide every building and all other HTW consumers with self-contained heating systems. That possibility is examined in this section.

Scope of Investigation

The economics of heating two conceptual buildings were analysed, based on use of the HTW system and use of self-contained systems. The buildings were the 10 unit, two storey residential building, and the 20 room, two storey hotel described earlier in the report. Construction of new buildings and conversion of existing buildings were both considered.

Estimates of construction costs were made using published cost data and estimating guides, with due allowance for the cost increases that would apply in Inuvik. Fuel and operations costs were derived from data described earlier in the report. Capital costs are described in the next section, and operations costs in the one following.

Capital Cost of HTW and Self-Contained Heating Systems

The facilities required to connect to the HTW system include a utilidette, typically 30 feet or so long, isolation valves, a control valve and heat exchanger. The secondary circulation system, including circulation pump, and the domestic hot water tank are common to both HTW and self-contained systems, so are not included in the estimates for either one. Table 15 shows the estimate of installed costs for an HTW connection.

TABLE 15

ESTIMATED COST OF CONNECTION TO UTILIDOR

Item	Residential	Commercial
Utilidette	0	0
Control valve	5000	5600
Heat exchanger	5000	6000
Domestic hot water exchanger	2790	3200
Piping, valves, misc.	6150	6150
Total	18,940	20,950

Notes:

(a) Estimated prices are installed, Inuvik, 1984.

(b) No cost of utilidette is attributed to the connection, since it is required in any case for water and sewage services. Utilidette HTW piping is included under "piping, valves, misc."

(c) Heat exchangers and control valves may be installed in the crawl space. Mechanical room space is not needed.

The facilities required in an independent system include a fuel tank and fuel supply system, two heating boilers and a domestic hot water boiler. In addition, valuable building space is allocated to a mechanical room.

An estimate of installed costs is shown in Table 16.

TABLE 16

ESTIMATED COST OF INDEPENDENT HEATING SYSTEM

Item	Building	
	Residential	Commercial
	(10 unit row house)	(20 room hotel)
Fuel tank, piping, pump	5,390	7,400
Boilers	14,640	19,380
Domestic hot water boiler	5,800	8,640
Piping, insulation, controls	10,070	13,380
Mechanical room	8,100	2,500
Electrical	4,800	4,800
Totals	48,800	56,100

Notes:

(a) Boilers are commercial quality, cast iron, forced draft.

(b) The residential building would require a mechanical room for the boilers. The commercial building's mechanical room containing ventilation equipment would have to be enlarged to accommodate boilers. Space is considered to be worth $45.00 per square foot.

Operations Costs

The principal operating expense with both systems is the cost of energy. In the first option, HTW heat is purchased from NCPC at a price which includes boiler plant and distribution losses, and overheads. In the second, fuel is purchased and then converted to heat energy, by means of a small facility somewhat less efficient than NCPC's industrial one.

Operations costs for the HTW system are shown in Table 17. Comparable costs for a self-contained system are shown in Table 18.

TABLE 17

OPERATIONS COST FOR HTW HEATING

Item	Building	
	Residential	Commercial
Annual heat load, MMBH	2434	4518
Annual hot water, MMBH	205	114
Total heat load, MMBH	2639	4632
Energy cost, $15.30/MMBH	$40,370	$70,870

Notes:

(a) $15.30/MMBH is NCPC's 1984 non-government charge rate.

TABLE 18

OPERATIONS COST FOR SELF-CONTAINED HEATING

Item	Building	
	Residential	Commercial
Annual heat load, MMBH	2,434	4,518
Annual hot water, MMBH	205	114
Total heat load, MMBH	2,639	4,632
Boiler efficiency	0.702	0.710
Hot water boiler efficiency	0.698	0.702
Fuel input, MMBH	3,763	6,527

Fuel cost, $10.62/MMBH	$39,950	$69,290
Electricity	570	450
	$40,520	$69,740
Annual maintenance	$ 90	$ 180
Maintenance, 5 year cycle	$ 3,000	$ 4,000

Notes:

(a) Fuel costs are based on 20 percent P40 (summer) at $.382/L and 80 percent P50 (winter) at $0.392/L, over the year.

(b) It is assumed that boilers would require cleaning and overhaul every five years.

Cost Summary

Capital and operations costs for supplying heat to the two buildings, from the HTW system and by independent heating facilities, are summarized in Table 19. Present values of 20-year costs are also shown, computed at a discount rate of 8 percent.

TABLE 19

CAPITAL AND OPERATIONS COSTS OF HEAT SUPPLY ALTERNATIVES, PRESENT VALUES, AND 20 YEAR CUMULATIVE COSTS

Cost	Building			
	Residential		Commercial	
	HTW	Self-Cont.	HTW	Self-Cont.
Capital, $	18,940	48,800	20,950	56,100
Energy, $/yr	40,370	40,520	70,870	69,740
Maintenance, $/yr	0	90	0	180
Maintenance, $/5yr	0	3,000	0	3,000

Present Value, 20 years

Capital, $	18,940	48,800	20,950	56,100
Energy	396,360	397,830	695,810	684,720
Maintenance	0	1,380	0	6,790
Total	415,300	448,010	715,760	747,610
Ratio	1.00	1.08	1.00	1.04

Comparison of HTW Heating to Self-Contained Heating

The estimates indicate that the cost of energy will be very nearly the same, whichever option is chosen. Since both the capital cost and the maintenance cost of a self-contained system substantially exceed the corresponding costs for the HTW option, economics very clearly favour the HTW option at current price relationships.

The similarity in energy cost between the two options is the result of several factors. The two systems use different fuels, having different heat contents and different prices; as well there are significant differences between the efficiency of large boilers and small ones.

The HTW boilers burn heavy fuel, having a heat content of 182,400 BTU/ig and costing $1.49/ig delivered to Inuvik. Self-contained systems burn P40 oil in summer and P50 in winter, both of which have a heat content of about 167,000 BTU/ig. P40 costs $1.74/ig, and P50 $1.78/ig. The cost of fuel delivered to the HTW system's boilers, including heating in the storage tank, is $8.34/MMBTU, while the equivalent cost to the private operator is $10.62/MMBTU, assuming 20 percent summer fuel and 80 percent winter fuel over the year. The price difference amounts to nearly 30 percent.

The energy efficiencies of the two options are about the same. The efficiencies of the large industrial boilers in NCPC's plant are in the neighbourhood of 82.5 percent, and delivery by the utilidor system averages 84.5 percent. Therefore, the yearly net of the entire HTW system is 69.7 percent. The best boilers available in the size ranges needed by the conceptual buildings achieve efficiencies in the range of 69.8 to 71 percent. When the power used by the self contained system to run draft fans and fuel pumps is added, the difference between the two systems in negligible.

Naturally, NCPC's non-government charge rate of $15.30/MMBTU includes energy losses throughout the system. In order to arrive at a comparable net energy cost for the self-contained system, the input fuel cost of $10.62/MMBTU must be increased by the reciprocal of efficiency, to $15.06/MMBTU. The energy costs for the HTW and self-contained systems appear to be within one or two percent of each other, at current price levels, a difference which is within the range of uncertainty in the estimates.

If (and only if) the energy costs for HTW and private heating are to remain essentially equivalent, then the question of which option is most economical devolves to a comparison of capital and maintenance costs. The comparison should include the difference in building space needs between the two systems.

As indicated in Table 19, the HTW system appears to be best in all respects. The capital cost of an HTW connection, control valve and heat exchanger is much less than the cost of a complete boiler installation. The HTW equipment will fit into a crawl space, while boilers require a dedicated mechanical room within the building. Finally, the HTW equipment is relatively simple and requires little maintenance, while periodic cleaning and overhaul of boilers is relatively expensive.

Some consumers have left the HTW system in recent years, in favour of self-contained heating. It has been reported that they believe that they recovered the capital cost of conversion within quite short periods.

The analysis just described contradicts any general body of opinion, should it exist, that the non-government price of HTW heat is significantly more than the equivalent cost of P40 and P50 heating oil. However, it does not necessarily contradict the experience of individual consumers who have left the system. The reason lies in the means of determining the amount of heat used by each building, for billing purposes. Since heat is not metered (metering is discussed elsewhere in the report), NCPC uses a heat loss factor calculated for each building, and the daily temperature records for each month, to estimate consumption and calculate the month's bill.

In 1982, NCPC recalculated the heat loss factors for all consumers in Inuvik, with considerable care. The calculation showed that many should be changed up or down by 25 to 50 percent, and some by more. It would appear that the billing factors now used probably do not reflect building energy performance as well as the 1982 ones might, inadvertantly to the advantage of some consumers and the disadvantage of others. The consumers who have disconnected almost certainly were members of the disadvantaged group; ones who had analysed their costs and determined that they could do much better by a change. If the owner of a building comparable to, say, the 10 unit conceptual residential building were to achieve a 20 percent reduction in energy costs, he would pay back the cost of conversion in seven years. In fact, the repayment period might be less, since the capital costs reported earlier were for a top quality independent heating installation, with 60 to 100 percent standby against failure of any component.

Energy is by far the largest component of the present value of total system cost, amounting to 87 to 97 percent of twenty year cost in the

cases considered, at a discount rate of 8 percent. If the discount rate (marginal, net after inflation) is reduced from 8 percent to, say, 4 percent, energy costs are in excess of 90 percent of the total. Therefore, the analysis is highly sensitive to any future variation in the relative price levels of different fuels. Specifically, it is sensitive to variation in the relationship between NCPC's retail price for HTW heat and the cost of the particular fuels used in self-contained heating systems.

In summary, the analysis shows that consumers will achieve least heating cost by staying on the HTW system, notwithstanding past experience in specific cases, if energy prices remain in present relationship.

Abandonment Cost

If for some reason it was decided to convert all consumers to self-contained heating and abandon the HTW system, capital costs would include

- the cost of providing self contained heating systems to approximately 243 consumers, and to the domestic water distribution system at selected new locations,

- the cost of insulating water and sewage pipes throughout utilidors now heated by HTW lines, and adding circulating pumps where needed, and

- the portions of capital costs of utilidor, boilers and other facilities net yet repaid, which might be written off.

Order-of-magnitude costs might be

- $8 to $11 million for new building heating systems, and
- $3 to $4 million for needed changes to water and sewer systems.

The total cost of $11 to $15 million does not include the remaining capital value of the HTW system which would be discarded.

Conclusions

It appears that the annual cost of HTW heat for a particular building should be about equal to the annual cost of the fuel that a self-contained heating system would use. However, the capital cost and the maintenance costs of an independent system, each exceed the equivalent cost for an HTW connection.

Therefore, existing consumers should achieve least overall heating cost by remaining on the HTW system. Similarly, it should in most cases be most economical to heat a new building being built adjacent to existing HTW utilidor by HTW heat, rather than independently. Finally, in some cases it might be cost-effective to convert existing buildings located adjacent to HTW utilidor from independent heating to HTW.

It is our impression that many residents of Inuvik believe that it is less costly to generate heat independently than it is to buy it from the HTW system. A widespread opinion of this sort could adversely affect the viability of the HTW system in future. Unit costs necessarily would rise if system loading were to decrease through departure of existing customers. It is suggested that NCPC may find it desirable to counteract misconceptions about heating economics, if they exist, through planned publicity.

Since the system appears to be cost effective, abandonment is not recommended.

These conclusions are based on the current non-government price for HTW heat, and current prices for P40 and P50 heating oil. The conclusions are extremely sensitive to any future change in relative price levels.

OPTION OF EXTENDING DISTRICT HEATING

Introduction

The conclusions of the preceding section raise the question of whether it might be cost effective to extend the HTW system throughout Inuvik, or into selected new areas.

Discussion

NCPC has advised that is does not own the utilidor system or the HTW distribution system, so it is to be presumed that distribution system capital costs are not covered by NCPC's $15.30/MMBTU HTW energy charge.* Consequently, the conomic analyses in the preceding section did not address the capital cost of main utilidor, either directly or indirectly.

*The replacement cost of the complete utilidor system carrying HTW mains, including water and sewer mains, but excluding any service connections, would be in the range from $25 to $40 million. If this seems a rather broad range, it might be remembered that recent bids for a certain section of utilidor proposed to be built at Norman Wells, carefully prepared in detail by professional estimators, ranged from $0.4 to $0.8 million.

The cost of building utilidors and the cost of installing HTW mains in utilidors are both very high. A utilidor complete with water and sewage mains may cost in the neighborhood of $250 to $350 per foot. A metal one carrying water, sewage and HTW lines might be $750/ft or more. Obviously, the capital cost advantage of HTW heat over a self contained system would disappear fairly quickly if much new utilidor had to be built, or an old one replaced, to bring HTW to a new customer.

At the same time, the relative importance of utilidor cost diminishes in proportion to the density of the load, so it might be found worthwhile to extend into a new area containing a high proportion of row housing, apartment buildings or other large consumers.

Conclusions

The high cost of building HTW distribution mains opposes the central heating system's cost advantages due to fuel efficiency, lower cost fuel and centralized maintenance of facilities.

The economics of extending the HTW system into some new area would have to be evaluated carefully, on the basis of the specific details of the proposal being considered. The evaluation would have to include an analysis of potential effects on existing consumers, and the heat generation plant.

EFFECT OF METERING HEAT

Introduction

Heat taken from the HTW system by consumers is not metered. Rather, NCPC estimates each customer's consumption using, among other data, the daily temperature record for the month.

Metering would improve billing accuracy, and perhaps increase customers' satisfaction with bills, at some cost. More importantly, it could encourage reasonable efforts to conserve heat, in any cases where such efforts are not already being made.

The objective of this section is to determine the feasibility and cost of metering.

Scope of Investigation

NCPC provided information on current billing procedures, and a copy of NCPC's 1982 report on building heat loss factors and hot water demand factors.

Concepts were developed for two different metering systems, "self contained" and "centralized". Five suppliers of instrumentation equipment reviewed these and provided comments and suggestions, and assistance with cost estimates.

NCPC provided information on a third type of system, "localized metering", which is also reported.

Current Practice

NCPC's current bills for HTW heat are based on separate calculations of heat used for space heating and heat used (if any) for domestic hot water heating.

Charges for space heating are based on the number of heating degree days in the billing period, multiplied by a calculated heat loss factor for the building.

Heat loss factors are calculated according to standard engineering methods. In 1982, NCPC inspected over 95 percent of the HTW consumer buildings in Inuvik, and recalculated all heat loss factors. Changes from those used previously were significant.

Charges for heating domestic hot water are based on the number of days in the billing period, times a daily use factor. Use factors have been calculated according to the number of persons normally occupying the building or dwelling unit. Again, these factors were reviewed in 1982, and changed where appropriate.

Discussion

The current practice has some significant advantages: it involves essentially no capital cost, and it also avoids the costs of reading meters and maintaining them.

It also has significant disadvantages. It is somewhat arbitrary, hence a potential cause of suspicion among customers. Because it is partially arbitrary, NCPC's bills are vulnerable to challenge. Finally, there is little or no incentive for homeowners and building occupants to practice reasonable conservation of heat, on a day-to-day basis.

Heat loss factor calculations are universally used for heating design and serve that purpose well. They are arbitrary in finer details, however, and it may be remembered that heating designers commonly allow a safety margin of ten percent or so in sizing equipment. In particular, ventilation loads may exceed the building's conductive heat losses, but may be hard to evaluate. In dealing with buildings already built, important factors such as the thickness of insulation, quality of vapour barrier and quality of the thermal envelope generally may be difficult or impossible to determine. It is also hard to keep track of building renovations.

Another potential disadvantage is the lack of motivation to use heat wisely. Once the building's heat loss and water heating factors have been established, the monthly charge amounts to a flat rate calculated uniquely for each building, varied only by factors beyond the occupant's control: the number of days in the billing period, and weather records. Consequently, there is no incentive to attempt to conserve heat, either in day-to-day household operation or through building maintenance and improvements.

While metering provides a wholly rational basis for billing, which reflects very clearly any success a consumer has in minimizing heat use, it does so at significant cost.

Two metering concepts were developed: "self-contained", in which groups of nearby meters are all connected to local reading station, and "centralized", in which all meters would "report" to a central computer facility. The concepts are described in the sections which follow.

Self Contained Metering

The self contained metering system would consist of a computer based "standalone" control unit (SCU), temperature sensors at the supply and return mains to each consumer and a pulse type turbine flow meter in the consumer's return main. Each SCU would be capable of metering up to six consumers. All heat consumption and totalizing would be done at the SCU units.

The SCU units would be located in the premises of one of the six consumers being metered. Each SCU requires 300 watts of electrical power, thus the consumer housing the SCU may require some reimbursement.

Temperature sensors would be installed at both the supply and return mains of each consumer. Preferably the sensors would be installed in the piping using thermal wells, however at some loss of accuracy the sensors may be contact mounted on the pipe surface and insulated over. Our cost estimates consider the thermal well method.

An alternate to sensing both supply and return temperature at each consumer is to sense return temperature only at the consumer, and supply temperature at the boiler plant. The rather small variation in supply temperature throughout the network may be then taken into account when computing the consumer billings.

The turbine flow meter installed in the consumer's return main (return prefered to supply because of lower temperature) would send electronic pulses to the SCU in relation to the flow rate.

Using data provided by the supply water temperature sensor, return temperature sensor and the flow meter, the SCU would compute the heat flow rate, using an appropriate algorithm. The time interval between calculations is software adjustable at the SCU to a minimum limit which is well within practical limits for metering accuracy. Each SCU would have sufficient computer memory to store consumption data for more than a month for each consumer.

A battery power back-up system (8 hour duration) would be provided for each SCU.

An interface cable would be run from the SCU to an electrical junction box at the consumer's building exterior. A portable computer terminal with integral printer would be plugged into this junction box to extract data on consumption from the SCU. When the data is extracted the consumption readings at the SCU may be reset (by software function) to 0 for all

consumers. Meter readings would be taken monthly. Entrance to the consumer's premises would not be required and reading one SCU would provide consumption data for six consumers.

Estimated costs for the installation of the self-contained metering system would be $1,582,000. Considering 256 consumers, the cost per consumer would be $6,180.00.

If this cost was to be recovered by increased billing costs over a period of 10 years, the billings would increase by approximately 3%.

Centralized Metering

The centralized metering system would be identical to the self-contained system described above except that a terminal plug in junction for the SCU's would not be used. Instead, the SCU's would be interfaced using a twisted pair serial data link to two central computers located at the power plant. IBM XT type central computers have been considered, one for each of the two main loops of the network. The central processors would each have a keyboard, display screen, printer, hard disk storage and floppy disk storage capabilities. The central computer would automatically poll the SCU's and obtain consumption data at regular intervals. Software would be developed to provide historic logging of consumption and record trends, and to print out actual bills.

Although not included in our cost estimating, software can readily be developed to facilitate statement and utility payment accounting which could also include electrical billings. Total estimated costs would be $1,849,000.00.

The cost per consumer would be $7,223.00 and would reflect an approximate increase of 3.5% in energy costs over a ten year period.

Localized Metering

NCPC has also given some consideration to the use of a totally self-contained design, the "Valmet" meter. The Valmet meter measures flow and inlet and outlet temperatures, and integrates flow and temperature difference continuously to provide an accurate summation of heat delivered. One complete meter including readout would be required for each consumer. The meter requires a 120 volt power supply.

NCPC's preliminary estimate of the cost of supplying and installing 200 Valmet meters is $440,000. By simple extrapolation, the cost for all 256 consumers (the figure used in estimating costs for earlier alternatives) would be $563,000.

The advantage of the wholly independant unit is lower capital cost. Its principal disadvantage is the need to read each consumer's meter on a regular schedule, at one or two month intervals. Another disadvantage is that the design does not lend itself to future conversion to centralized reporting.

It is also thought that the computer based systems described earlier might require less maintenance, however, there is no information available to support or disprove this hypothesis.

Conclusion

The capital cost of meters is likely to be in the neighborhood of $0.6 to $1.9 million, $2200 to $7500 per unit.

Metering might achieve significant gains in heat conservation. It is probable that it would be well received by consumers, and could be a factor in encouraging consumers to stay on the HTW system.

EFFECT OF CHANGING FUEL

Introduction

Currently, Inuvik's electricity and heat generation systems burn two classes of oil, "heavy" (No. 5, Bunker C) and "light" (P40). Heavy fuel is supplied by barge from Norman Wells, while P40 is imported from Alberta and shipped by barge from Hay River. The heavy fuel costs less per unit volume from the supplier, but on the other hand needs to be heated before it can be pumped through fuel lines, burner nozzles and injectors.

As described earlier, the HTW boilers burn heavy fuel. The "K" plant generators can use either, but are also normally fired by heavy fuel. The new EMD plant engines require light fuel. NCPC used them very little in 1984, once they were commissioned, owing to a perception that it is more expensive to generate power with light fuel than with heavy. It is understood that they are being used more now.

One objective of this section is to compare the cost efficiency of heavy fuel and P40 fuel, for generation of power and generation of heat.

A considerably broader issue is the effect that development of the oil and gas resources now known and still to be discovered in Inuvik's vicinity could have on fuel costs there. It seems fairly certain that alternative supplies and alternative types of fuel will at some time become available, at costs below what would then apply to existing sources. In fact, the cost of bringing natural gas from the Parsons Lake field to Inuvik has already been examined at least twice, by R.N. Dalby and Associates Ltd. in 1978, and by Stone & Webster Canada Ltd. in 1984. In addition, Gulf Canada Resources Inc. provided information following on Stone & Websters' work, in correspondence to the Government of the Northwest Territories in August 1984.

The broader questions of future fuel economics and fuel choices are beyond the scope of this study, but the principal findings of the R.N. Dalby and Stone & Webster reports and Gulf's comments are included in this section.

Scope of Investigation

The comparison of light and heavy oil fuels was based on

- 1984 fuel prices,
- approximate thermal content of both fuels (BTU/ig; BTU/lb) (a parameter which is subject to some variance),
- operating characteristics of each engine and generator at different load factors and, in the case of the K engines, on the two different fuels, and
- hourly electrical load for an average year, with 1984 customers, synthesized as described earlier.

The average cost of fuel per kwh generated was determined, for each type of fuel, taking into account variation in efficiency due to variation in load. Fuel cost included fuel heating cost. Total annual fuel costs for exclusive use of light fuel and heavy fuel were then determined, and compared.

With respect to possible future changes, the R.N.Dalby and Stone & Webster reports and Gulf Canada's comments were reviewed, and the principal findings of each are included in this section.

Comparison of Light and Heavy Oil Fuels

The choice between light and heavy fuels would affect the cost of fuel paid to the supplier and the cost of heating fuel prior to use. It has been assumed that other costs, such as the cost of maintaining engines,

would not materially change, there being at present no evidence from NCPC to the contrary. Costs for light fuel and heavy are compared in Table 20.

TABLE 20

COMPARISON OF FUEL COSTS FOR ELECTRICAL GENERATION

Parameter	Heavy Fuel No. 5	Light Fuel P40
Fuel cost, landed at Inuvik, $/ig	1.488	2.021
Fuel heating cost, average, $/ig	.033	.000
Total fuel cost $/ig	1.52	2.02
Thermal content of fuel, MMBTU/ig	0.1824	0.167
Cost of fuel $/MMBTU	8.34	12.10
Average engine efficiency, BTU/BHP hr	6,195	6,182
Average generation efficiency, BTU/KWH	10,092	10,071
Average fuel cost of electricity, $/kwh	.084	.122
1984 cost of fuel if entirely heavy	$3,180,644	
1984 cost of fuel, actual	$3,488,800	
1984 cost of fuel if entirely light	$4,617,682	

These estimates indicate that the cost of P40 used in the engines is 45 percent higher than the equivalent cost of heavy fuel.

No separate analysis of the choice of fuel for boilers has been done. Cost differences would be parallel and similar.

Future of Natural Gas

The following sections contain relevant excerpts from the R.N. Dalby and Stone & Webster reports, and from Gulf Canada's submission to the Government of the Northwest Territories. It must be borne in mind that each report reflects the forecasts, predictions and perceptions current at the time of writing.

R.N. Dalby & Associates Ltd., March 1978

R.N. Dalby & Associates Ltd. was retained by the Town of Inuvik to examine the economics of bringing natural gas to Inuvik from gas fields then known; in particular from the Parsons Lake field.

The findings of the R.N. Dalby study are self-explanatory, and are repeated below in entirety.

"1. Northern Canada Power Commission has an agreement with Imperial Oil Limited under which it is committed to use heavy fuel oil purchased from the Norman Wells refinery. This agreement can be terminated by Northern Canada Power Commission on December 31, 1980.

2. If the Dempster pipeline was to be placed in service in January 1985 this pipeline would provide the lowest and most dependable energy supply for the Town of Inuvik.

3. The Parsons Lake gas supply is the closest known natural gas supply source for the Town of Inuvik. Because of the high capital cost of the facilities

required for natural gas production, dehydration, removal and disposal of liquid hydrocarbons and the potential for serious operating problems associated with gas production and liquids disposal, Parsons Lake is not considered to be a very attractive source of natural gas for Inuvik. If, however, a decision is made to study in depth the cost of providing natural gas from an isolated gas supply source (an isolated supply being a supply that is not connected to a transmission system carrying natural gas from more than one source of supply) a detailed comparative cost study should be made of Parsons Lake, Ya Ya and any other potential supply which may be discovered in the Inuvik area as a result of new exploration activity.

4. Natural gas service from the Gulf Oil Canada Limited Ya Ya field could over the long term provide lower cost energy to Inuvik than liquid fuels purchased from the Norman Wells refinery.

5. If the construction of the Dempster pipeline is considered to be a fair to good possibility it would not be prudent to invest millions of dollars in a natural gas system, based on the Gulf Ya Ya supply, or some other natural gas supply some distance from Inuvik, for once an investment is made in a utility project the costs must be borne by the consumer even if a lower cost supply becomes available at some later date.

6. Northern Canada Power Commission has indicated that low cost hydro-electric energy could become available

to Inuvik sometime in the future. Such a development would have a positive impact on the cost of electric energy for the Inuvik power consumer. However, if a natural gas system had been installed prior to low cost hydro-electric energy being supplied to Inuvik, natural gas rates would have to be increased when hydro-electric energy became available as the capital investment and operating costs for the natural gas system would have to be spread over fewer sales.

7. With hydro-electric energy being a future possibility it would be in Inuvik's interest to keep any capital investment related to natural gas service to a minimum. This can best be realized through obtaining natural gas from the Dempster pipeline or some other pipeline constructed to transport Mackenzie valley natural gas to markets.

8. The energy requirements that could be served by a Parsons Lake liquids pipeline are too small to support the 8" liquids pipeline that was being considered by Gulf Canada Limited."

Stone & Webster Canada Ltd., March 1984 and May, 1984

Stone & Webster Canada Ltd. was retained by the Government of Canada and the Government of the Northwest Territories to examine the economics of supplying communities along the Mackenzie Corridor, including Inuvik, with natural gas. The follow-up report dated May, 1984, was confined to the economics and feasibility of developments which the first study had identified as potentially viable, one of which is the possibility of bringing natural gas or liquid hydrocarbons from Parsons Lake to Inuvik.

Stone and Webster's analysis used existing fuel costs, the capital cost of conversion to a new fuel, and the somewhat reduced operations costs offered by natural gas, to calculate an "equilibrium price" for natural gas below which a rational consumer would find it attractive to convert and above which he would not. Equilibrium prices derived for different classes of consumers, projected to the year 1986, are listed in Table 21.

TABLE 21

EQUILIBRIUM FUEL PRICES, 1986

(From Stone & Webster Canada Ltd., 1984)

Consumer Type	Equilibrium Price $/GJ	Existing Price $/GJ
Residential	8.58	9.18
Commercial	11.35	9.18
Power Plant	9.51	10.18

They then calculated wellhead costs, and capital and operating costs for a gas treatment plant and a transmission facility from Parsons Lake to Inuvik. The cost study indicated that gas could be brought to Inuvik and sold there at or below the "equilibrium price," with reasonable returns. Stone and Webster concluded that "under most likely conditions, gas is economically viable for Inuvik, and would not require government support."

It was assumed, in reaching this conclusion, that if gas were to become available at a price attractive in comparison to oil, the cost of conversion included, then most or all customers would convert to gas within a relatively short time.

Gulf Canada Resources Inc., August, 1984

Following distribution of Stone & Webster's report, Gulf Canada Resources Inc. staff made an independent assessment of the cost of bringing gas to Inuvik, with and without concurrent transmission to Tuk. The analysis considered different levels of financial incentive that might apply. Mr. J.K.S. Loh, of Gulf Canada, summarized Gulf's estimates and findings in a letter dated August 24, 1984 to Mr. Peter Hart of the Energy, Mines and Resources Secretariat of the Government of the Northwest Territories. Conclusions included the following, reproduced with the kind permission of Mr. Loh.

> "Combined production and delivery costs would result in "Town Gate" prices, for Inuvik, in a range from $15.55/GJ to $8.10/GJ. The lower numbers could only be achieved with full fiscal relief and favourable throughputs. Distribution costs must also be added to the above rates.
>
> At present, liquid fuel delivered to Inuvik is estimated to have a cost of $12.75/GJ.
>
> Our analysis suggest that gas supply from Parsons Lake to Inuvik and Tuktoyaktuk would not be attractive at this time. Even with full fiscal relief, we do not see the delivered price of gas being sufficiently attractive to encourage conversion from liquid fuels."

Discussion

The effect that arrival of natural gas in Inuvik might have on the HTW system is difficult to predict. While consumers with private heating systems and those served by the district heating system might both benefit

from a lower fuel price, it may be significant that Stone & Webster's equilibrium price for NCPC's powerhouses is markedly lower than the equilibriun prices for other consumers. If the eventual price for gas at Inuvik were to fall between the equilibrium prices for different types of consumers, then some might convert and others might not. On the other hand, it would seem unlikely that a gas supply system could be made economical without including such a large consumer as NCPC among its list of intended customers.

Conclusions

Heavy fuel is, at the current relationship between prices, substantially more economical than P40 for generation of both electricity and heat.

The studies that have been done indicate that the benefits of natural gas supply to Inuvik would be greatest if the supply was tapped from a transmission main to the South, as compared to building a small gas plant and transmission main solely to serve Inuvik. Opinions appear to be divided on the question of whether an independent supply serving Inuvik alone would be viable.

PART IV

PREPARATIONS FOR ANALYSIS OF WASTE HEAT RECOVERY

INTRODUCTION

NCPC's power station at Inuvik produces electricity for both Inuvik and Tuktoyaktuk. The average on a typical February day is about 5.18 Mw. The fuel efficiency of diesel generation is usually about 35 percent, so the total heat being lost from generation at the 5.18 Mw demand rate is in the neighborhood of 32,900 MBTUH. For comparison, the concurrent typical February day loading carried by the HTW system boilers, due to both consumers and utilidor losses, is in the neighborhood of 53,300 MBTUH. Of course, much of the 32,900 MBTUH generation loss is not recoverable.

For various reasons, a substantial portion of the heat wasted from electrical generation cannot be recovered and put to such uses as building heating. There are efficiency losses in recovery equipment; much of the heat is available at temperatures too low to be used directly for many purposes, and excessive cooling of engine exhaust gases causes stack corrosion problems, difficult and costly to solve. In the usual case, some heat can be recovered readily, at modest cost, but the cost per unit of energy recovered goes up as the proportion recovered is increased.

The engine cooling systems in NCPC's new EMD plant are arranged so that some heat is recovered and used to heat the plant and the combustion air supplied to the engines. Currently, there is no recovery from engine cooling in the much more heavily used K plant, or from engine and boiler stacks in either plant.

If heat could be recovered at suitable temperatures, the HTW distribution system provides an obvious means of transporting it to consumers.

Furthermore, it might be possible to increase the amount recoverable by lowering the temperature of the HTW system, or by raising the operating temperatures of the engines, or even by increasing the temperature of recovered heat by a heat pump system. Recovery and distribution of waste heat would probably involve major changes in the powerhouses and to the HTW distribution system.

These matters are the subject of Parts IV and V of Volume II. Part IV describes work done in preparation for analysis of alternatives, and Part V describes the analyses themselves and conclusions. The principal objective of the preparatory analyses of Part IV is to assess the quantities and temperatures of waste heat produced during generation of electricity and heat, hourly, daily and over the operating year.

GATHERING AND COMPILING OF DATA

Plant and Facilities

Information on the powerhouses was complied from engineering drawings kindly made available by NCPC, from inspections of the plant and from discussions with NCPC staff.

As described earlier, simplified schematic drawings of HTW piping, powerhouse fuel heating, fuel supply, engine cooling and engine coolant heat recovery systems were prepared, and checked in the field.

Engine manufacturers were asked to provide certain data and advice with respect to increasing jacket, oil and valve cage operating temperatures.

Operational Characteristics

The operational characteristics of the district heating system have been described earlier. Parallel information of the electrical generation plant was obtained from

- monthly records of heavy and light fuel use by K and EMD engines, respectively, 1982 through 1984,
- monthly records of electrical energy produced for the power grid, April, 1976 to April, 1984,
- continuous chart recordings of power generation for periods of days representative of different seasons, and
- operations personnel.

The use of this information is described below.

PREPARATORY ANALYSES

Studies of the district heating system have been described earlier. Similar preliminary studies were done to compile and generate information on power generation, needed for investigation of waste heat recovery options. The more significant of these are described below.

Generator Characteristics and Energy Balance

An energy balance was developed for each of NCPC's five generator sets (engine and generator combined), for 50, 75 and 100 percent loading, using

information provided by manufacturers. Heat lost through cooling the engine lubricating oil, valve cages, engine jackets and the generators, and heat lost through engine stacks and radiation, was all accounted for, along with energy produced (shown as its thermal equivalent).

The energy balance for engine KV16 is typical and is show in Figure 25. As can be seen, the way in which input energy is distributed changes over the loading range, so some care was taken to formulate a realistic engine scheduling plan and realistic load profiles.

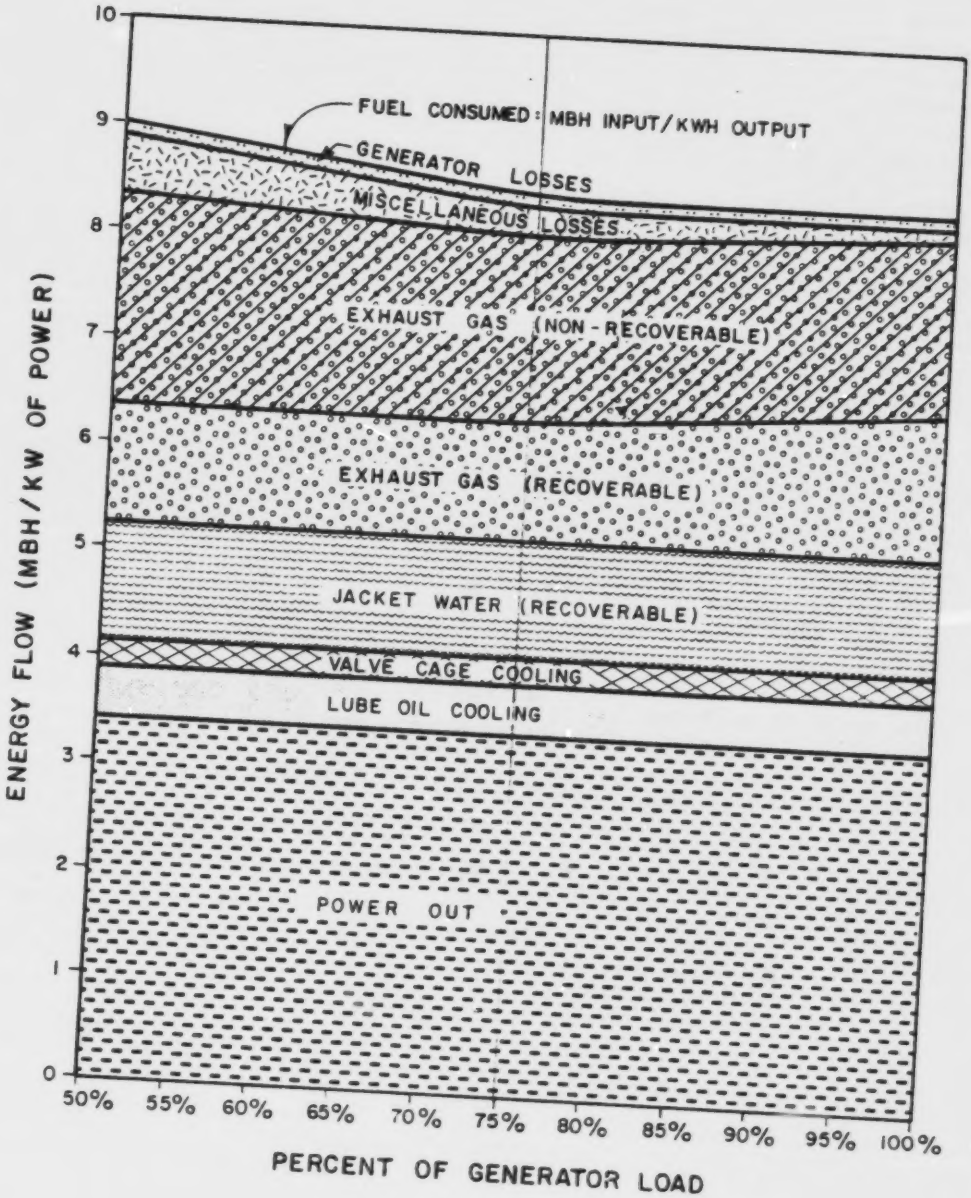
Engine Scheduling

The capacity of each generator set and useful combinations of generator sets are shown in Figure 26.

As described earlier, NCPC considers the heavy fuel burning K engines to be more economical than the newer EMD units. Operating records indicate that the division of load between K and EMD engines has varied considerably, but the recent trend has been toward much heavier reliance on the K plant. Therefore, it has been assumed that where economical load ranges overlap, K engines would be used 90 percent of the time and their EMD counterparts 10 percent of the time.

The hypothetical generator set use schedule is shown in Table 22.

KV-16 ENGINE ENERGY BALANCE

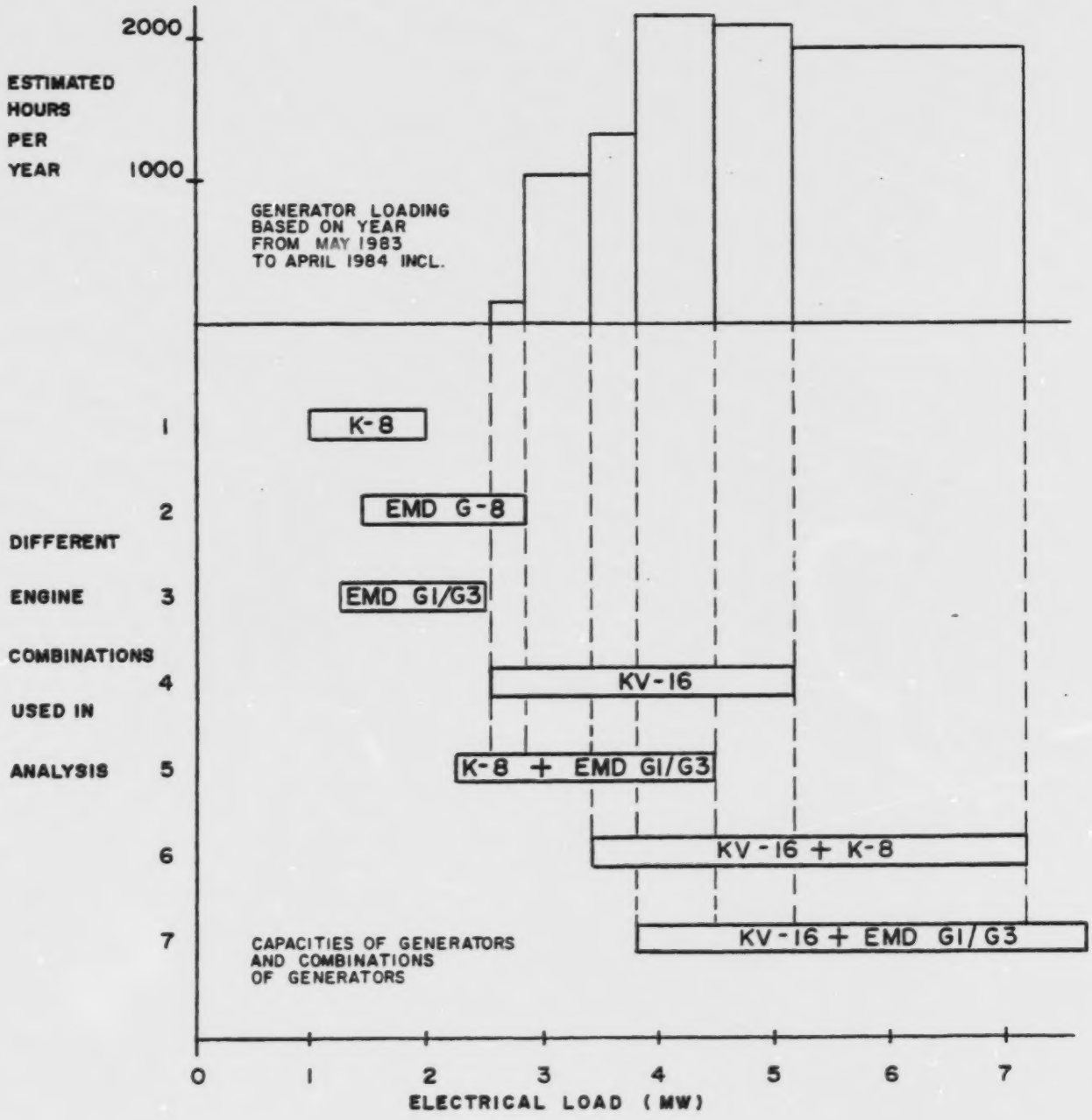


INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 25

ELECTRICAL GENERATOR LOADING AND CAPACITY



INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 26

TABLE 22

HYPOTHETICAL GENERATOR SET SCHEDULE

Generator	Load
	Mw
K8	1.0 - 2.0
EMD G-8	1.425- 2.85
EMD-G3 (G8)	1.25 - 2.5
KV-16	2.6 - 5.2
K-8 & EMD-G3 (G8)	2.25 - 4.5
KV-16 & K8	3.6 - 7.2
KV-16 & EMD G3(G8)	3.85 - 7.7
K-8 & EMD G1/G3	2.25 - 4.5
KV-16 & EMD G1/G3	3.85 - 7.7

Electrical Load Profiles

NCPC's continuous chart records of power generation reveal the range of diurnal variation in power demand at different times of the year, and confirm the fact that diurnal variation can be approximated by a sine curve. These findings and the monthly records for a number of years were used to synthesize a respresentative hourly demand record spanning a full year. In turn, the synthetic year's record was used to develop load-frequency profiles for the full year, for each month and for other periods of interest. The method paralleled the development of temperature frequency profiles, described earlier for boiler loadings.

Electrical Generation Energy Balance

Energy balance data for individual generators, the generator scheduling table reported earlier, and the electrical load profile were used to

calculate the total energy balance for electrical generation for a year, for each month, and for shorter periods as needed to determine the matching between recoverable waste heat and potential uses of waste heat. The net annual energy balance for electrical generation is shown in Figure 27. Electrical energy is shown as its thermal equivalent.

Total Energy Balance for Each Powerhouse

The electrical generation energy balance data described above and the heat generation energy balance data reported earlier were each broken down between the K and EMD powerhouses, and then HTW and electrical generation energy flows were combined. The energy flow scheme for the K plant is shown in Figure 28, and for the EMD plant in Figure 29.

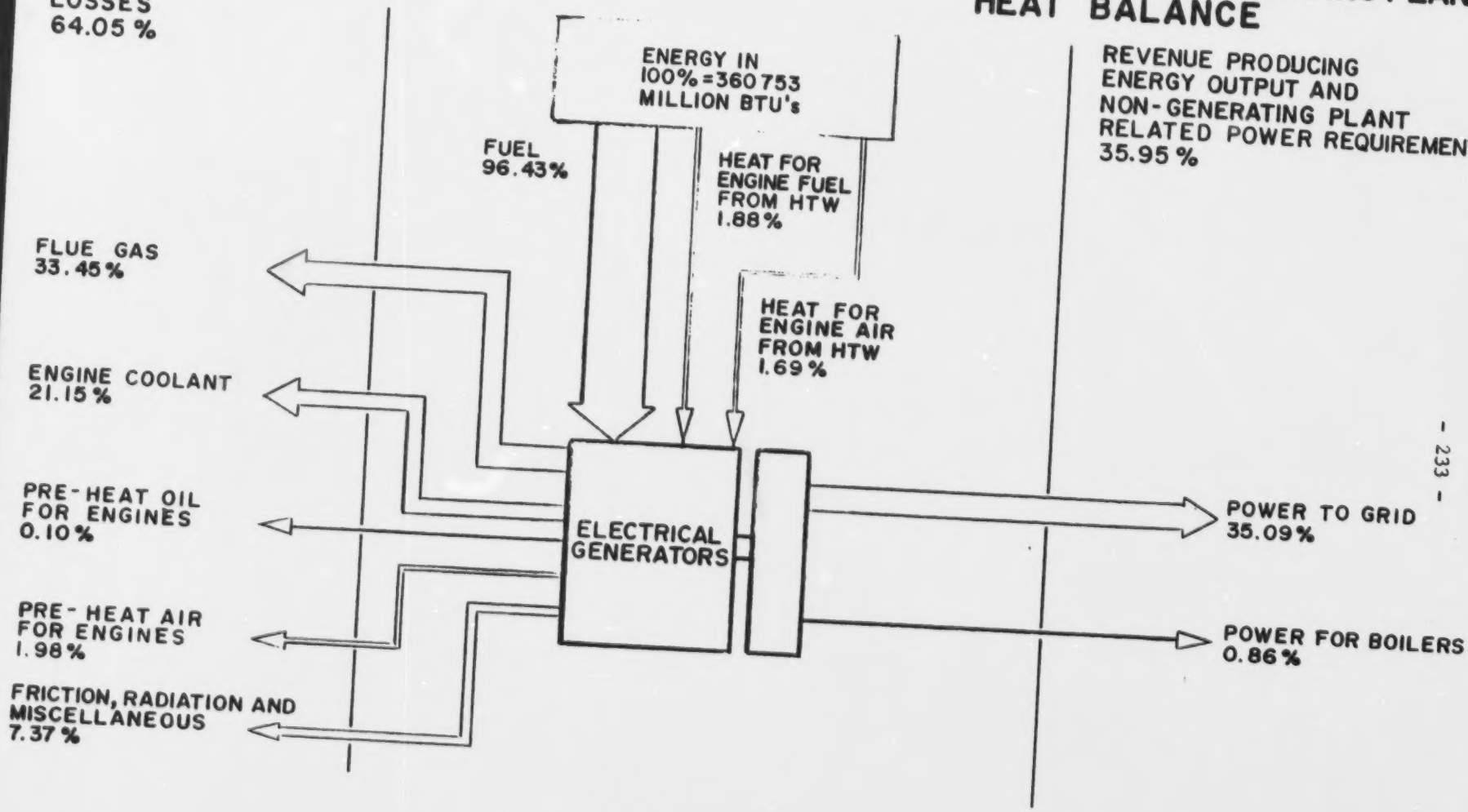
Division of Cost Between Fuel and Overhead

As reported earlier, HTW heat is sold at $15.30/MMBTU to non-government consumers (14 percent of total heat sold), and at $16.65/MMBTU to government (86 percent of total) yielding a weighted average revenue of $16.46/MMBTU. The current cost to NCPC of the fuel burnt to deliver 1 MMBTU of HTW energy to customers, including the small amount used by diesels to produce electrical energy consumed in the process, is $12.10.

Obviously, the remaining $4.36/MMBTU contributes to NCPC's operations cost apart from fuel, and to maintenance, capital cost and overhead. It is known that NCPC's rates are intended to recover the full amount of cost, and it is assumed that this objective was being accomplished in Inuvik's case, in 1984. For the purposes of the study, $4.36/MMBTU has been considered to be the total 1984 amount of all costs involved in generating and delivering HTW heat, aside from fuel.

The electrical rate structure is more complex than the two-category one for heat. However, similar logic has been applied. It is calculated that

ELECTRICAL GENERATING PLANT HEAT BALANCE

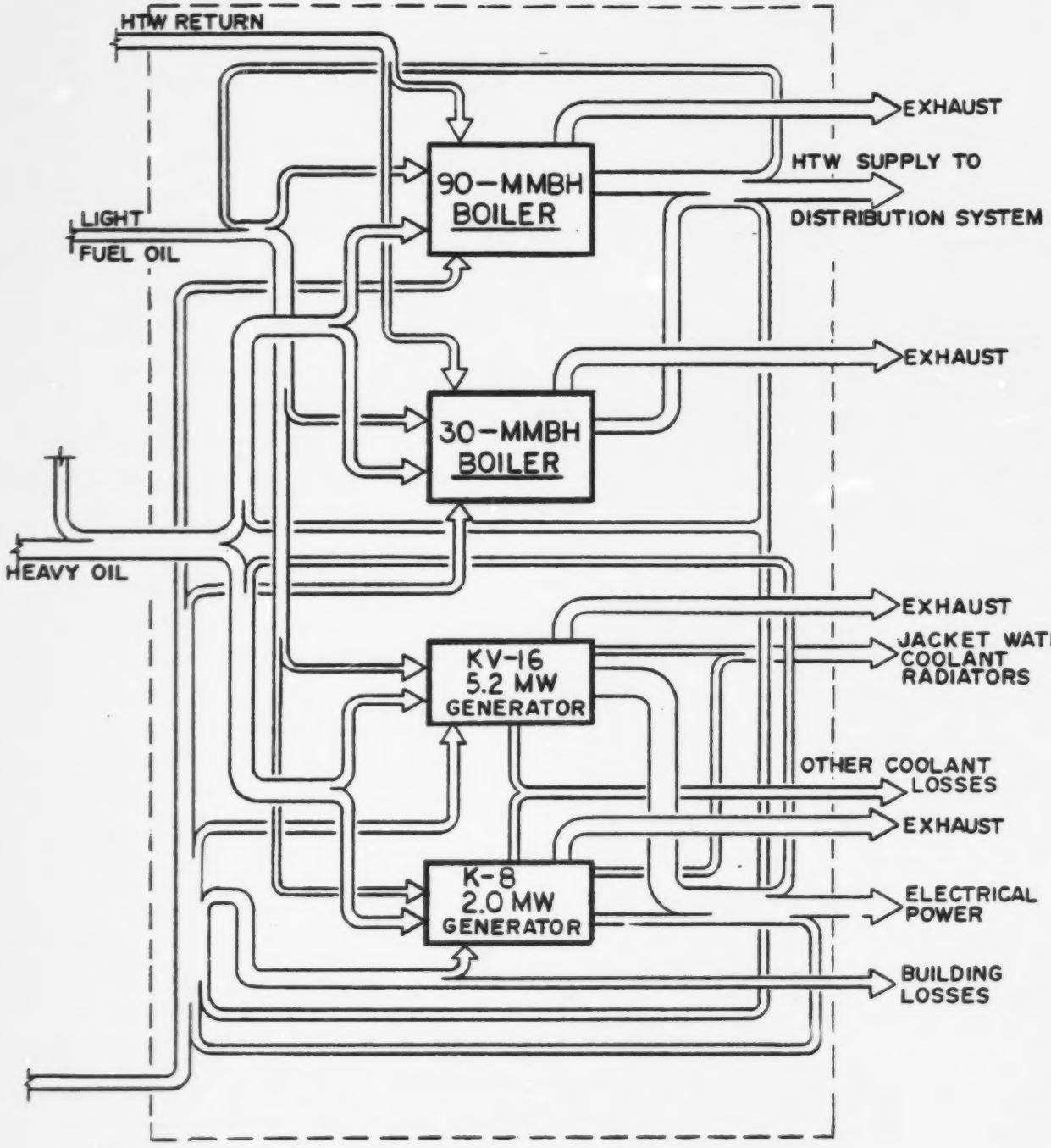


INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 27

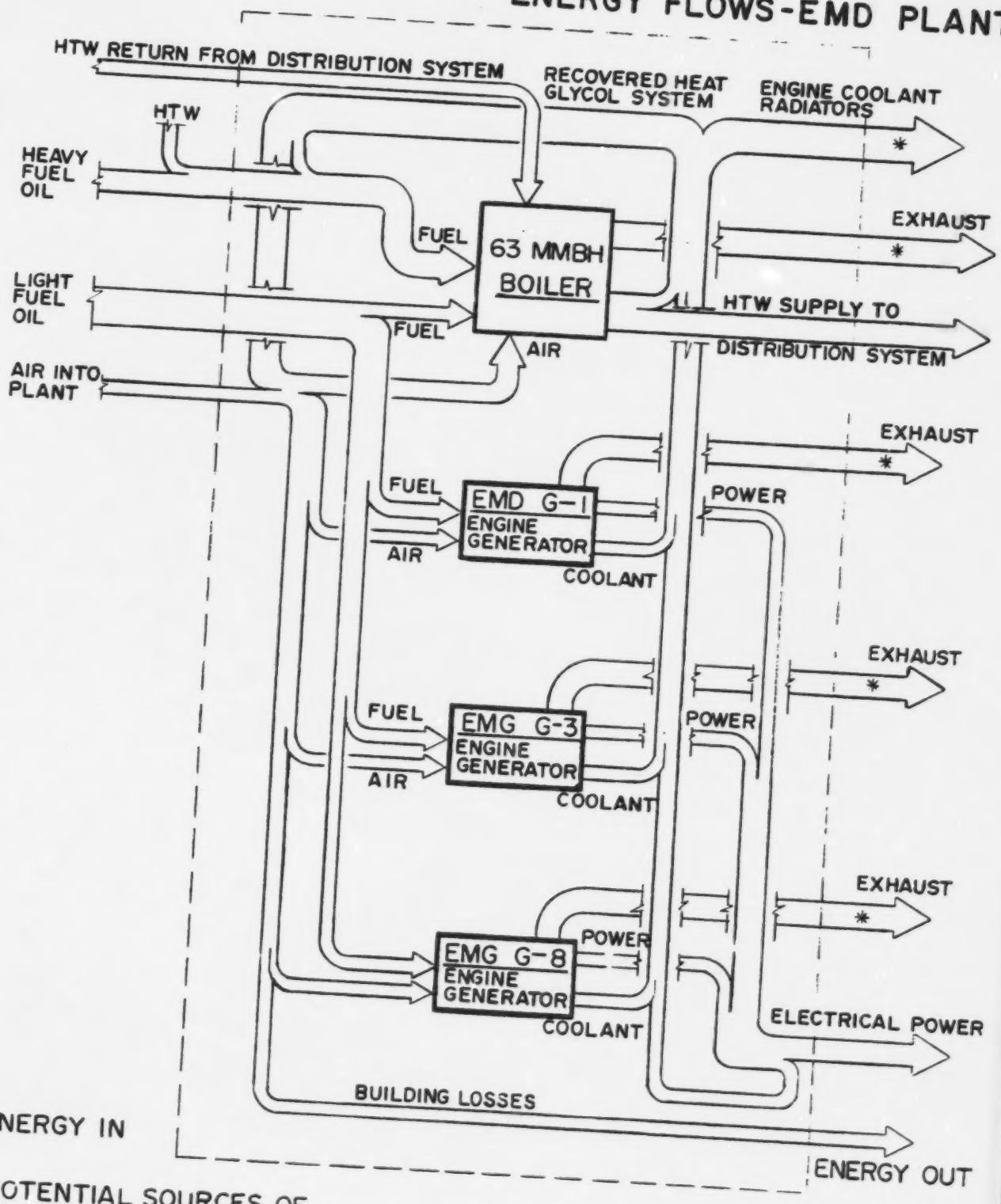
ENERGY FLOWS K-PLANT



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 28



INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 29

NCPC's average charge for electricity is $0.2456/kwh, and that the average cost for fuel is $0.0991/kwh (considering that about 57 percent of elctricity now sold is generated in the K plant, and 43 percent in the EMD plant). It is assumed that the remaining $0.1465/kwh is a true reflection of all costs, except fuel, in generating and delivering power.

PART V
ANALYSIS OF WASTE HEAT RECOVERY

INTRODUCTION

Significant quantities of heat are lost from the powerhouses through boiler and engine stacks, and through exterior radiator cooling systems which keep the diesel engines at their designed operating temperatures. These losses represent a substantial fuel expense. The total amount of fuel needed for generation of both electricity and heat could be reduced, if ways could be found to capture some of the waste heat and deliver it to some useful end purpose.

Unfortunately, it is both complicated and costly to recover and distribute waste heat from diesel generators. It is essential that any recovery system protect the engine from changes in temperature, so supplementary cooling would be needed to discard waste heat which exceeded the amount needed by consumers. Conversely, supplementary heating would be needed for the times when the quantity of waste heat recovered fell short of consumers' needs. Obviously, the capital cost of the equipment and piping and controls systems needed for recovery of heat, supplementary cooling and supplementary heating is substantial, and the operations and maintenance cost may be significant as well. The distribution system needed to deliver recovered heat from the powerhouse to consumers may also represent a considerable expense.

There are also difficulties in finding an end use for recovered waste heat. First, although the quantity of energy recoverable may be quite large, its temperature may be so low that it cannot be used for many purposes. Second, the amount of waste heat generated fluctuates diurnally and seasonally, in response to fluctuations in the demand for electrical

energy. Heating loads and electrical loads follow rather different patterns, so there is difficulty in finding a consumer, or group of consumers, whose heat requirements are reasonably well matched to heat availability throughout the year.

Part V begins with a description of the quantities, temperatures and other characteristics of waste heat flows that now occur in NCPC's powerhouses. Next, possible uses of waste heat are described, with a view to finding a good match between availability and need. Finally, various concepts for recovery and distribution of waste heat are developed, described and analysed, and conclusions drawn.

SOURCES AND CHARACTERISTICS OF WASTE HEAT

Introduction

Heat lost in flue gases is relatively high in temperature and large in quantity, but the amount recoverable is small. Heat rejected from the cooling systems of engine jackets, valve cages and lubricating oil is large in volume but relatively low in temperature.

In addition to the large losses just mentioned, heat also escapes as radiation from engines, boilers and piping (in spite of insulation being applied wherever appropriate), through air cooling of generators and pump motors, and in other minor ways. Most of these smaller losses perform some useful work, in winter at least, in heating the powerhouses. In any case, they have to be accepted, since there is no practical means of reducing them significantly or of recovering the energy.

This section provides information on the principal sources of waste heat, the quantities produced, temperatures, possible means of recovery, and any particular limitations on recovery.

Boiler Stack Losses

It may be remembered that boiler flue losses account for 13.5 percent of the fuel energy put into the district heating system. The annual loss is 61,000 MMBTU, representing $502,000 in fuel cost.

The usual temperature of boiler flue gases is 390 to 450°F, 110 to 170°F above the temperature of water being returned to the boilers by the HTW distribution system.

There are two significant obstacles to recovery of heat from boiler flue gases. First, the equipment is costly, relative to the quantity of heat that might be obtained. Second, cooling of flue gases can lead to condensation, and acid corrosion of the stack and the heat recovery tubes.

A search was made for equipment designed for heat recovery from boiler stacks, and correspondence opened with manufacturers. Important parameters in the design of such equipment are the flue gas dew point temperature, and the acidity of the condensate if temperatures fall below that level. Manufacturers reviewed analyses of the heavy fuel used in Inuvik, which has a sulphur content of 3.5%, and boiler operating data.

The conclusion reached is that the flue gas temperature which might reasonably be designed for using conventional materials, is 400°F. Reducing the temperature to this level would not recover enough heat to repay the cost of the installation.

The allowable temperature fall can be increased somewhat, to below the water saturation temperature, if highly corrosion resistant heat recovery tubes are used. However, the cost of the equipment rises at least as fast as the value of returns.

It was concluded that it is not practical to attempt to recover heat wasted from boiler stacks.

Engine Stack Losses

Engine stack losses account for 33 percent of the fuel put into Inuvik's electrical generating facilities. The annual loss is 121,000 MMBTU, representing $1,167,000 in fuel cost.

Engine exhaust temperatures vary with load, over ranges which vary widely between different makes of engine. The amount of heat that can be recovered is, as in the case of boiler exhausts, limited by the need to keep exit temperatures safely above the dew point and thereby avoid acute corrosion difficulties. The safe temperature for the engine exhausts would be between 350 and 400°F,* depending on the choice of engine and the electrical load.

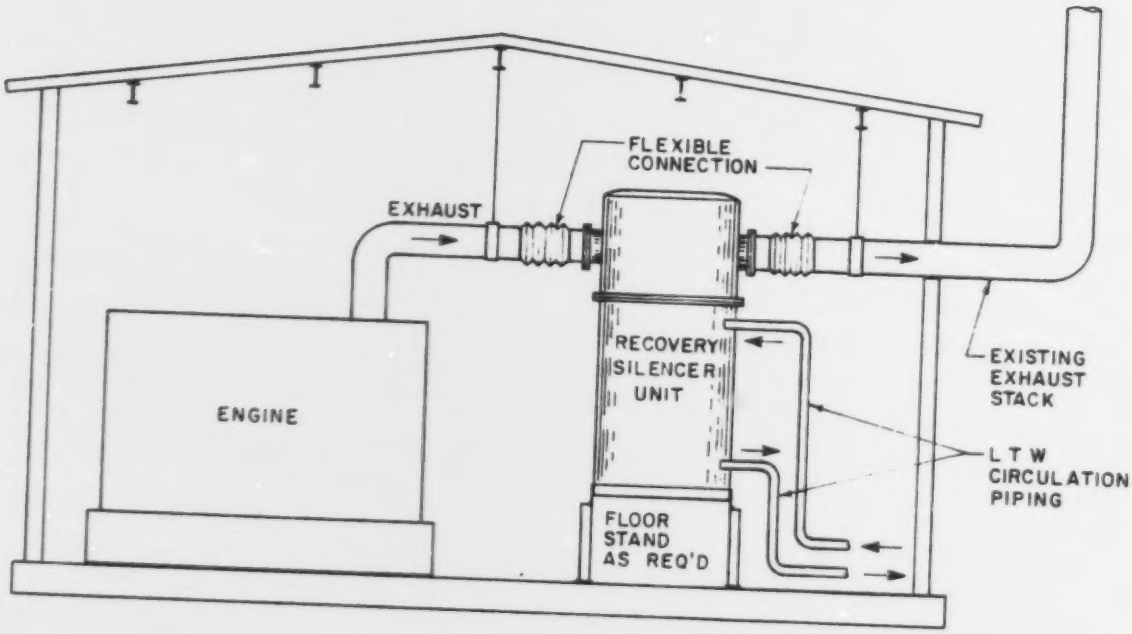
Engine stack heat recovery is usually combined with silencing, in a unit such as the "Maxim" heat recovery and silencing system manufactured by Riley-Beaird. Data published for the Maxim unit has been used in analyses. The general arrangement of a recovery-silencer is shown in Figure 30.

According to preliminary estimates, up to 43,500 MMBTU/yr, 36 percent of the total now being lost, might be recovered from engine exhausts. All of this heat would be available at temperatures above the operating temperature range of the HTW system.

Recovery of heat from engine exhausts appears to be promising, and is included in analyses described later.

*Data from engine manufacturers.

ENGINE STACK RECOVERY - SILENCER



PHYSICAL LAYOUT (SECTION)
OF EXHAUST HEAT RECOVERY BOILER

INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

N.T.S.

VOL. II FIGURE 30

.ne Jacket and Valve Cage Cooling

Engine cylinder jackets and engine valve cages are cooled by separate coolant flow loops. A heat exchanger on each coolant loop discharges heat into an exterior radiator glycol circuit. In the EMD plant, heat is taken back out of the radiator circuit and used to preheat the P40 fuel used by the EMD engines, and to heat the plant.

Engine jacket and valve cage cooling accounts for 15.5 percent of the fuel supplied to the generators. The total amount of heat removed from the engines is 55,900 MMBTU/yr, of which 3000 to 5000 MMBTU is recovered and used in the EMD plant as described. The total rejected through the radiator systems in both plants is 52,000 MMBTU/yr, representing $502,000 in fuel cost.

Jacket water enters the EMD engines at 180°F, and leaves at 195°F. Glycol enters the coolant heat exchanger at 130°F, and leaves at 150°F. In the case of the K engines, jacket water is intended to enter at 160° to 170°F, and leave at 180°F; actual entering and leaving temperatures recorded in February, 1984 at unit KV-16 were 156°F and 168°F.

Heat from jacket and valve cage cooling is not expensive to recover. The flow circuits exist, and so do heat exchangers if they are to be used. The radiator systems are available as backup and to assist with matching. Corrosion and cross contamination problems and risks are small, and not difficult to address. Essentially the entire amount of 52,000 MMBTU/year would be recoverable, if a suitable consumer of low temperature heat could be found. Obviously, however, low temperature is the principal limitation in recovery and use of heat from this source. The waste heat recovery concepts described later seek to overcome that limitation.

Engine Lubricating Oil Cooling

The lubricating oil used in the diesel generators is cooled by a glycol system which discharges heat to an external radiator cooling circuit.

Lubricating oil cooling accounts for 5.65 percent of the fuel supplied to the generators. The total amount of heat rejected and wasted is 20,380 MMBTU/yr, representing $196,700 in fuel cost.*

Lubricating oil reaches a temperature of 175°F within the engine, and is cooled to 150 to 155°F. A temperature gradient is needed to exchange heat from the oil to the cooling fluid (glycol); consequently, heat from this source is available at temperatures around 145 to 150°F.

The low temperature, the relatively small quantity and the risk to the engine of cross-contamination combine to make this source less attractive than others. It has not been included in analyses which follow, but should be reconsidered in any pre-design study of waste heat recovery.

Summary and Conclusions

Heat is lost through boiler and engine stacks, and through cooling of engine jackets, valve cages and lubricating oil.

It would not be cost effective to recover heat from boiler stacks.

Engine stack losses amount to 121,000 MMBTU annually, of which 43,500 MMBTU/year, 36 percent of the total, might be recovered, at temperatures above 350°F. The fuel value of potentially recoverable heat is $420,000 per year.

*A small amount of this heat is used for building heating, in the K plant.

Engine jacket and valve cage cooling losses now amount to 52,000 MMBTU annually. All of this heat could be recovered, at temperatures down to 160°F.

Lubricating oil cooling losses amount to 20,400 MMBTU annually. All of this heat could be recovered, at temepratures down to 150°F. Limitations on the use of this source include low temperature, and the need to protect engine lubricating oil from cross-contamination. This possible source is not considered further, in this study.

Recovery of some of the heat normally wasted from engine stacks and through engine jacket and valve cage cooling appears to be promising. Concepts for distribution and use are described later in the report.

POSSIBLE USES OF WASTE HEAT

Introduction

A problem in using recovered waste heat is that if any substantial amount is recovered, its temperature will probably be low in relation to the HTW system's temperatures, and low, too, in relation to the temperatures usually found in building heating circuits. The ideal consumer for waste heat is one requiring a fairly steady, large inflow at temperatures preferably below about 160°F.

This section describes the findings of a search for suitable consumers.

Powerhouse Service

The powerhouses require heat for warming of building spaces, preheating of combustion air and heating of heavy and light fuel. Heating of fuel in storage tanks is considered separately.

The K plant requires 1290 MMBTU/month for space heating during coolest months, and the EMD plant needs 860 MMBTU/month. The EMD plants needs are satisfied by recovered jacket water heat when the EMD engines are running, and both the plants are heated to a considerable degree by heat unavoidably lost from boilers, engines and piping. The amount of heat actually supplied by the HTW system for plant building heating is estimated to be only 621 MMBTU/year. Therefore, space heating of powerhouses would consume, at most, a small amount of the heat which might be recovered.

In the EMD plant, combustion air for the engines is heated using waste heat recovered from engine cooling. In the K plant, HTW heat is used for this purpose. The amount used, however, is small, and amounts to less than 1 percent of the amount of waste heat that might be recovered.

Heavy fuel is heated by HTW within both plants, to a temperature of 190°F in the case of the heavy fuel burnt by the boilers. Heat requirements total about 1022 MMBTU/year, equivalent to only 1.2 percent of the waste heat that might be recoverable. The P40 oil used in the EMD plant is heated by waste heat recovered from engine cooling.

Fuel Tank Heating

Heavy fuel is heated in its storage tanks, near storage tank outlets, and in outdoor fuel lines, to reduce viscosity to the point where the fuel can be pumped. Currently, high temperature water flows directly through tube bundles installed in the tanks.

The requirement for heat is reasonably constant during the winter, reaching 1700 MBH during the coldest months. It is estimated to total about 15,200 MMBTU/yr, equivalent to 16 percent of the waste heat likely to be concurrently recoverable. Use of waste heat might make it

necessary, however, to replace the tube bundles now in the tanks with larger ones, to compensate for the drop in supply temperature.

Municipal Water Treatment Plant and Water Distribution System

Water supplied to Inuvik's municipal water system is heated by up to 5°F during cold weather, at the water treatment plant located adjacent to NCPC's powerhouse. The requirement for heat is relatively constant at about 960 MBH, whenever the temperature is below -20°F, equivalent to 8.4 percent of the waste heat likely to be concurrently recoverable. No heat is added when the outside temperature is above -20°F. However, the addition of a clarification stage to the plant will in future add a requirement of about 950 MBH during spring and fall.

The heat exchangers now in the water plant are sized for the existing 350°F supply, and would probably have to be replaced if a change were made to waste heat.

Heat is also added to the water at several scattered locations in the distribution system, the demand at -30°F being about 970 MBH. Although the temperature of the domestic water makes it a very attractive sink, there is no obvious way of bringing recovered heat out to the places in the distribution system where it is needed.

High Temperature Water Heat Distribution System

The operating characteristics of the HTW system have been described earlier. High temperature water is supplied to the distribution system at 350°F and returns at 250 to 270°F. The quantities of heat consumed range from 11,700 MMBTU/month in July to 43,200 MMBTU/month in February. For comparison, the quantities of waste heat that might be recoverable concurrently range from 3,200 MMBTU/month in July to 6,200 MMBTU/month in February.

Transfer of heat recovered from engine stacks to the HTW system would be relatively easy. A portion of the HTW return flow could circulate through engine flue gas heat recovery tubes, with the amount of flow being controlled to maintain an exit temperature of 350°F. The remainder of the HTW return flow would be directed through an HTW boiler, and reheated as is done now.

Unfortunately, transfer of the potentially much larger volume of jacket and valve cage heat to the district heating system is much more difficult. Coolant approaches the engines at a temperature of 155°F to 165°F, and leaves at temperatures of 180°F to 185°F (the K and EMD engines having slightly different operating ranges). These figures are far below the coolest return temperature that could be achieved in the existing HTW system.

The possibility of raising engine operating temperatures to improve heat recovery prospects has been discussed with representatives of the manufacturers, Midwest Power Co. in the case of the EMD engines and Hawker Siddley Canada Ltd. in the case of the K engines. Manufacturers do not recommend that engine temperatures be increased more than 5°F above the recommended limits mentioned above. A possible increase of this amount does not enhance prospects for matching jacket heat to the HTW system.

Summary and Conclusions

The high temperature heat recoverable from engine flue gases could be transferred directly to the HTW distribution system, with little modification of current operations.

Potential uses of the low temperature heat recoverable from engine cooling include powerhouse service, warming of water at the municipal water treatment plant and warming of fuel in storage tanks. Lack of a suitable

distribution method rules out use of low temperature heat for freeze protection of the water system at points remote from the powerhouse area.

The quantities of heat that could be used by low temperature consumers amount to less than 25 percent of the low temperature heat likely to be concurrently recoverable.

The economics of recovering engine flue gas heat for use in the HTW system, and of recovering engine cooling heat for use by low temperature consumers are discussed in the sections following.

RECOVERY OF ENGINE STACK HEAT FOR HTW SYSTEM

Introduction

It is technically feasible to recover engine stack heat and transfer it to the HTW system. The economics of that option are discussed in this section.

This concept does not address the potential for recovery and use of engine cooling heat.

Concept Description

Flue gas heat recovery units, such as the Maxim unit mentioned earlier, would be installed on all five diesel engines.

Piping would be arranged to divide the flow of water returning from the HTW distribution system between a stack heat recovery inlet header and the HTW boiler inlet header. Inflow to each recovery unit would be controlled continuously to maintain an exit temperature of 350°F. All flow not taken

by recovery units would be reheated by the duty HTW boiler, exactly as is done now.

On a monthly basis, the HTW system can use all of the heat that might be recovered by this arrangement. However, diurnal fluctuations in demands for heat and electricity might occasionally create a need to waste some recovered heat, in summer months. External cooling would be needed in these circumstances, to prevent overheating HTW water. Provision for external cooling would involve drawing a portion of the HTW flow leaving recovery units through the existing radiator heat rejection system or through a heat exchanger interfaced to that system, and returning the cooled stream to the recovery piping ahead of the recovery unit. Each such cooling loop would require a small circulation pump.

It is estimated that this arrangement would recovery approximately 32,000 MMBTU/year.

Cost Analysis

The capital cost of heat recovery equipment, piping and controls is estimated to be $2,850,000. The estimate is summarized in Table 23.

TABLE 23

CAPITAL COST OF ENGINE FLUE HEAT RECOVERY SYSTEM

Item	Cost
Heat Recovery Equipment	$ 2,350,000
Standby cooling	220,000
Piping and Pumping	280,000
Total	$ 2,850,000

Notes

(a) Costs have been developed using published data for southern locations, increased to account for the costs of transport, of import and housing of a skilled labour force, and of a long work week.

(b) Costs are inclusive of engineering and normal contingencies.

The value of the heat expected to be recovered is approximately the equivalent fuel cost of the same amount of heat produced by boilers for the HTW system.

The 1984 cost of fuel used to generate one year's supply of HTW heat, exclusive of fuel used to generate the electricity used by the HTW system, is estimated to be $3,670,000. The amount of heat delivered to the powerhouse wall is 359,000 MMBTU, resulting in a unit value for recovered heat, also delivered to the powerhouse wall, of $10.22/MMBTU.

If the amount of fuel that must be wasted throughout the year is negligibly small, then the value of heat saved would be $317,500 per year.

The simple payback of an investment of $2.85 million at $317,500 per year would require 7.6 years. At a discount rate of 8 percent, the payback period would be 12.7 years.

Conclusions

While recovery of waste heat from engine flue gases for use in the HTW distribution system appears to be cost effective, the payback period would be long.

Economic projections are highly sensitive to future variations in relative price levels and to uncertainties in cost estimates. On the whole, this concept does not seem to be particularly attractive.

RECOVERY OF ENGINE COOLING HEAT FOR LOW TEMPERATURE USERS

Introduction

It is technically feasible to distribute engine cooling heat to low temperature users, such as fuel tanks and the water treatment plant, rather than wasting it to atmosphere as is now done. The economics of this option are discussed in this section.

Concept Description

A separate, low temperature heat distribution piping system would be built in the NCPC yard area, from the powerhouses to the tank farm and to the water plant. The existing heat distribution piping to fuel tanks would be incorporated into this system.

The low temperature heat distribution system would be interfaced to the existing engine cooling systems through heat exchangers, which would be located ahead of the existing radiator systems in the engine cooling loops. Cooling heat not taken by low temperature consumers would be rejected through the radiators, as is done now. The heat recovery system would be prevented from cooling the engine cooling systems below normal operating levels.

The quantities of heat rejected always, or nearly always, exceed the amounts needed by low temperature consumers. The low temperature consumers require about 24,300 MMBTU/year. The system described would recover essentially all of that amount.

Cost Analysis

The capital cost of heat recovery equipment, piping, exterior piping, and controls is estimated to be $973,000. The estimate is summarized in Table 24.

TABLE 24

CAPITAL COST OF ENGINE COOLING HEAT RECOVERY SYSTEM

Item	Cost
Equipment	$ 310,000
Supplementary cooling: exists	0
Distribution header; pumping	180,000
Distribution network	480,000
Total	$ 970,000

Notes

(a) Costs have been developed using published data for southern locations, increased to account for the costs of transport, of import and housing of a skilled labour force, and a long work week.

(b) Costs are inclusive of engineering and normal contingencies.

The value of heat expected to be recovered by the system, at $10.22 MMBTU, is $248,300. Operating costs, mainly use of electricity, would amount to $48,000 per year, and annual maintenance is estimated at $18,000. Therefore, the net annual saving would be in the range of $182,000 per year.

The payback period would be 5.3 years, simple, and 7.2 years at a discount rate of 8 percent.

Conclusions

The use of engine cooling heat by low temperature consumers appears to be more promising than recovery of heat from engine stacks. Again, however, economic projections are sensitive to uncertainties in estimates and future price levels.

As described earlier, it would not be difficult to recover all of the heat rejected through engine cooling. The difficulty lies in finding uses for it.

The concept just described makes use of about 47 percent of the total of 52,000 MMBTU/year which might be available, over and above the 3900 MMBTU/year now recovered and used. It appears that use of the majority of recoverable engine cooling heat would require either its transfer to the HTW system by means of a heat pump, or its distribution to a group of consumers having equipment adapted as needed to use it.

Heat pumping and low temperature heat distribution concepts are described in sections which follow.

DEVELOPMENT AND ANALYSIS OF HEAT PUMP CONCEPT

Introduction

A heat pump uses gas-liquid phase change to transfer heat from a source at lower temperature to sink at higher temperature. Power must be supplied to drive the system, usually in the form of electricity.

Preliminary Analysis

Fundamental principles of thermodynamics set maximum limits on the efficiency of heat transfer cycles, which may be approached but never actually realized by carefully designed equipment. The limiting "coefficient of performance" (or COP) of a theoretical heat pump (Carnot) cycle, which is the ratio of the energy successfully transferred to the power used in doing it, is a function of the temperatures of source and sink. For the temperatures under consideration, the limiting COP is about 3.4.

Due to various losses, the efficiency of real equipment would be less than 3.4; in fact probably less than 2.0. However, the preliminary analysis is based on 3.43, in order to establish a most favorable limiting case.

The large KV-16 engine rejects 800 BTU/BHP hr through jacket water; 5.7 MMBTUH at full load. Although it is difficult to find heat pumps rated higher than 0.2 MMBTUH, availability is assumed. An energy flow of 5.7 MMBTUH would require a pump drive motor of nearly 1000 hp. The input energy would be 2.35 MMBTUH.

NCPC sells HTW heat energy at an average cost of $16.46/MMBTU. If energy were saved, then fuel would be saved in direct proprtion, but it is unlikely that plant overhead costs would be reduced. Nevertheless, energy saved is valued at $16.46/MMBTU in the preliminary analysis, to establish a limiting most favorable case. On this basis, recovery and use of 100 percent of 5.7 MMBTU from cooling water would save $93.82/hr.

NCPC sells electrical energy at an average cost of $0.2456/kwh, equivalent to $71.98/MMBTU. The much higher cost reflects, among other things, the unavoidable inefficiencies in diesel generator sets. At this price the cost of the theoretical minimum energy input, 2.35 MMBTU, would be $168.84/hr.

Conclusions

The preliminary analysis indicates that the ratio of cost recovery to operating cost, achievable with a theoretically perfect heat pump, and with recovered heat valued at full heat production cost, would be 0.56. The actual ratio would be closer to 43 percent, considering the probable efficiency of a heat pump, and the likelihood that recovery of waste heat would reduce fuel cost but not plant overhead. This return would be reduced further by capital costs, including the cost of increasing total generating capacity to run the heat pump equipment.

Heat pumping is not cost effective. This concept is discarded.

DEVELOPMENT AND ANALYSIS OF LOW TEMPERATURE HEAT LOOP CONCEPT

Introduction

Typical operating temperatures for a hot water baseboard radiation heating system are 200°F supply, from a boiler or heat exchanger, and 180°F return.

Engine coolant operating temperatures are lower: for the K engines 150°F to 160°F approaching and 180°F to 185°F leaving; for the EMD units 150°F approaching and 180°F leaving. These temperatures are not high enough to operate conventionally designed baseboard radiation systems to full intended capacity.

However, jacket water heat could be made useful for heating buildings if combined with heat from a higher temperature source, such as heat recovered from engine stacks.

Concept Outline

It is thought that a low temperature heat distribution system might be operable, within the temperature regime described below. The fluid would be a glycol mixture suitable for flow directly through engine cooling chambers.

1. The low temperature water and glycol mixture would return from the distribution system at 150°F to 160°F.

2. It would pass through the jacket and valve cage cooling chambers of any K engines being operated, leaving at 180°F.

3. It would next pass through heat recovery systems in the stacks of operating K and/or EMD engines, leaving at 230°F to 240°F.

4. It would pass through a heat exchanger where heat would be added, if necessary, from the HTW system to ensure exit temperatures of 230°F. This unit would operate if not enough heat were available from the recovery system.

5. It would pass out through distribution mains installed in new or existing utilidors, reaching consumers at 225°F to 240°F.

6. It would pass through consumers' heat exchangers sized to return it at 155°F.

It will be noted that the concept provides for recovery of jacket heat from the K engines but not the EMD units. The EMD units are little used, and when they are, some of the rejected jacket heat is used for plant service purposes. Furthermore, the EMD engines' cooling systems are so designed that connecting into them without use of existing heat exchangers

(and consequent loss of the small temperature gradients that exist) would be difficult and expensive. It would be worthwhile if pre-design studies are launched to reconsider the economics of additional heat recovery from EMD engine jackets, but preliminary estimates have indicated that it would not be cost effective.

Provision must be made to add heat to the conceptual low temperature water (LTW) heat distribution system from the HTW system whenever demand exceeds the amount of heat being recovered. Provision must also be made to reject any amount of jacket heat produced in excess of demand, to protect the engines from overheating.

Development of Recovery Concept

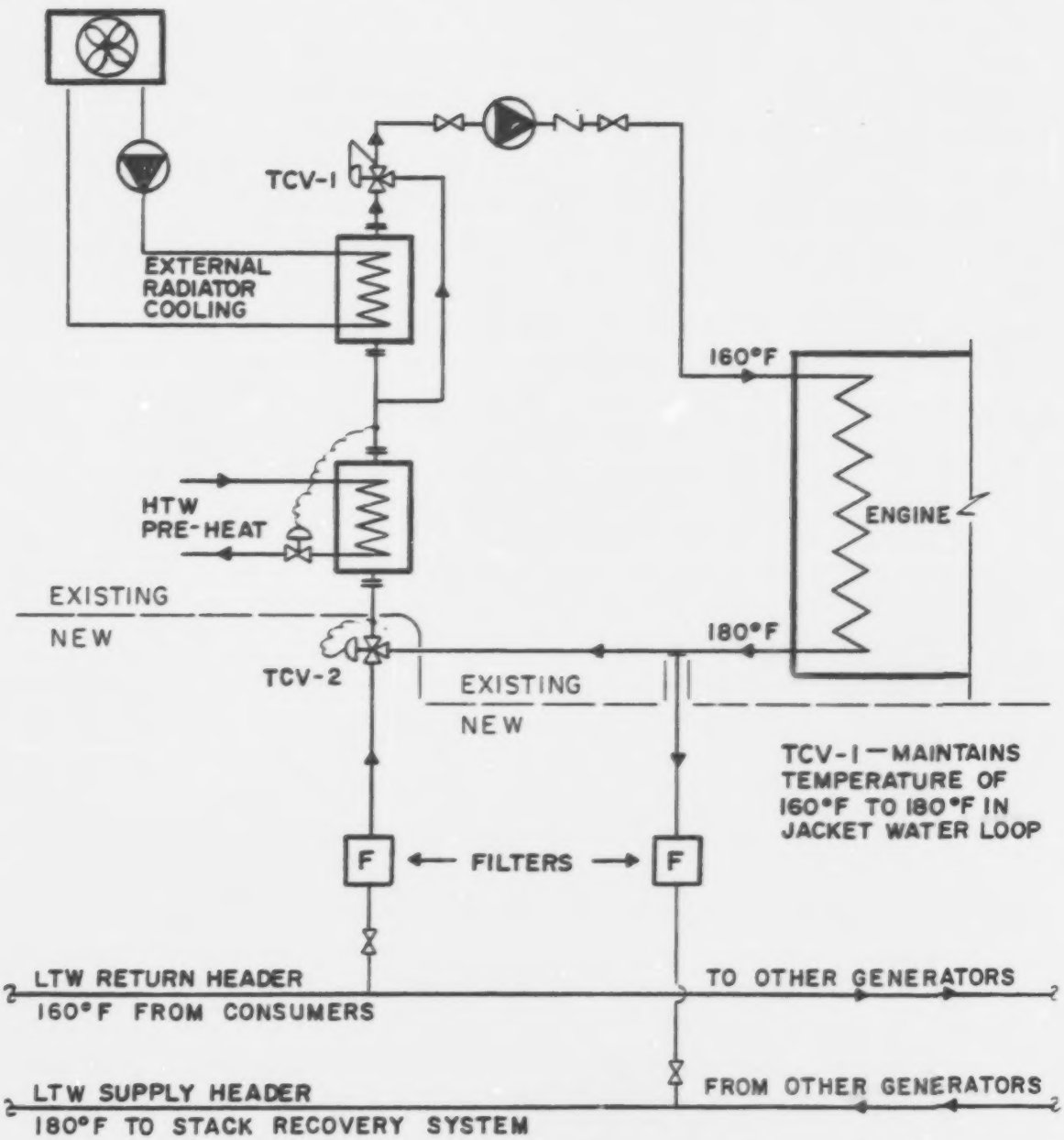
Separate systems for recovery of waste heat from engine jackets and engine stacks are shown in Figures 31 and 32 respectively.

Most of the equipment shown in Figure 31 is in place, being the existing engine jacket cooling system. New piping and equipment includes the LTW return and supply piping, the two LTW filters, and control valve TCV-2, the function of which will be explained.

As the cooling system exists now, 180°F glycol leaves the engine and passes directly to the "HTW preheat" heat exchanger, since control valve TCV-2 is not in the circuit at this time. The preheat exchanger uses HTW heat to keep the engine cooling circuit (and therefore most of the engine itself) at 160°F whenever the engine is not being run, to prevent thermal shock on startup.

From the preheat exchanger, the circuit branches through and around the heat exchanger shared with the external radiator cooling circuit. The glycol coolant in the external radiator circuit circulates continuously.

ENGINE JACKET WATER HEAT RECOVERY FLOW SCHEMATIC

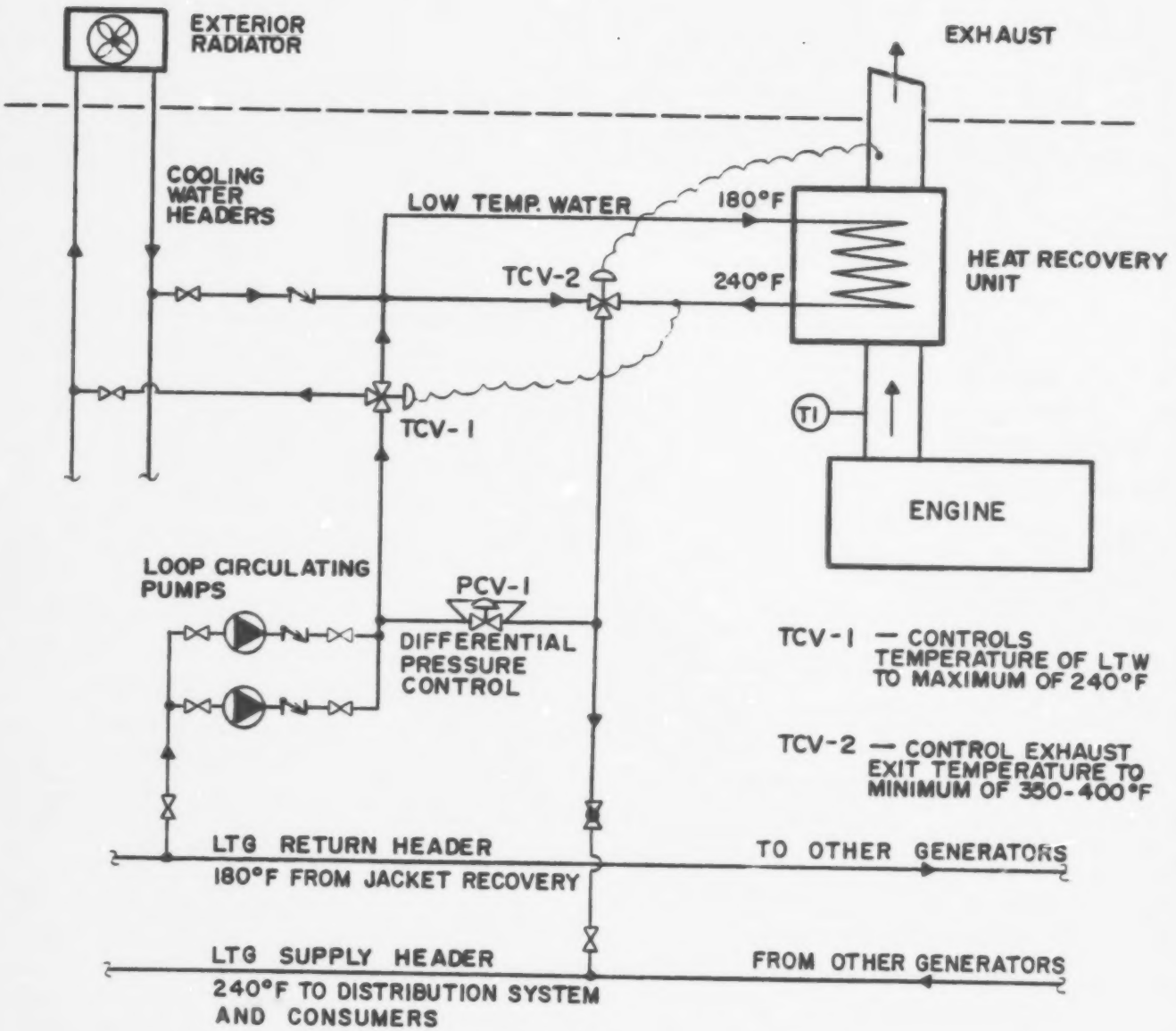


INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 31

TYPICAL ENGINE EXHAUST HEAT RECOVERY FLOW SCHEMATIC



HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 32

Control valve TCV-1 is set to proportion flow between the heat exchanger and bypass branches so that the mixed temperature is 160°F.

The circulating pump beyond TCV-1 runs continuously, whenever the engine is in use or on standby.

As described next, adding an LTW heat recovery circuit would change these arrangements only in minor ways. Most essential, the reliability of the existing cooling system would not be compromised.

The LTW circuit would be connected to the pipe which runs between the engine and the preheat exchanger, as shown. The new modulating three-way control valve TCV-2 would control the interaction between the LTW system and the pre-existing cooling circuit. In one position ("closed"), the valve would stop all flow from the LTW return header to the cooling circuit, and the cooling circuit would operate exactly as it does now. At the other extreme, all flow would originate at the LTW return header, pass through the engine circuit, and emerge at the LTW supply header as 180°F "heated" low temperature water.

TCV-2 would operate in response to the temperature in the cooling circuit just downstream of the LTW connections. It would be fully open at temperatures between 160°F to 175°F, making the cooling circuit part of the LTW system. It would proprtionally close over the temperature ranges 175°F to 180°F and 160°F to 155°F. Proportional modulation is intended to prevent any abrupt temperature change in the cooling circuit.

The HTW preheat and exterior radiator cooling systems would continue to function, if called upon, just as they do now. Their plant and engine cooling functions would not be changed.

While it might be hoped that stack heat could be recovered with fewer complications than those described with respect to engine cooling, the

schematic (Figure 32) indicates that such is not the case. A controlled connection to an exterior radiator circuit is needed so that heat recovered by the system in excess of that taken by the LTW distribution system can be expelled. Controls are also needed to keep the recovery system from overcooling the stack and incurring corrosion problems.

The function of the pressure differential control PCV-1 is to ensure that there is always some flow in the LTW distribution system. The two control valves TCV-1 and TCV-2 modulate to maintain temperature in the various branches of the recovery piping within acceptable limits. The interaction of TCV-1 and TCV-2 would have to be considered very carefully during pre-design of any proposed system. It may also be possible to combine the external cooling arrangements with existing equipment.

Analysis indicates that these systems could recover 4175 to 9930 MMBTU/month from K engines and stacks and EMD stacks.

Development of Distribution Concept

It has been established that much of the waste heat recoverable would have to be used to heat existing buildings; ones now having HTW connections and conventional baseboard radiation.

The demand for electrical power rises in the winter and declines in the summer. However, the seasonal change in demand is not nearly so dramatic as the seasonal variance in heating load. Consequently, the waste heat available from power generation is a larger proportion of HTW system demand in summer than it is in winter, being about 37 percent in July and 20 percent in February.

If an LTW system were developed, existing HTW customers would be transferred to LTW in sufficient numbers to match heat availability.

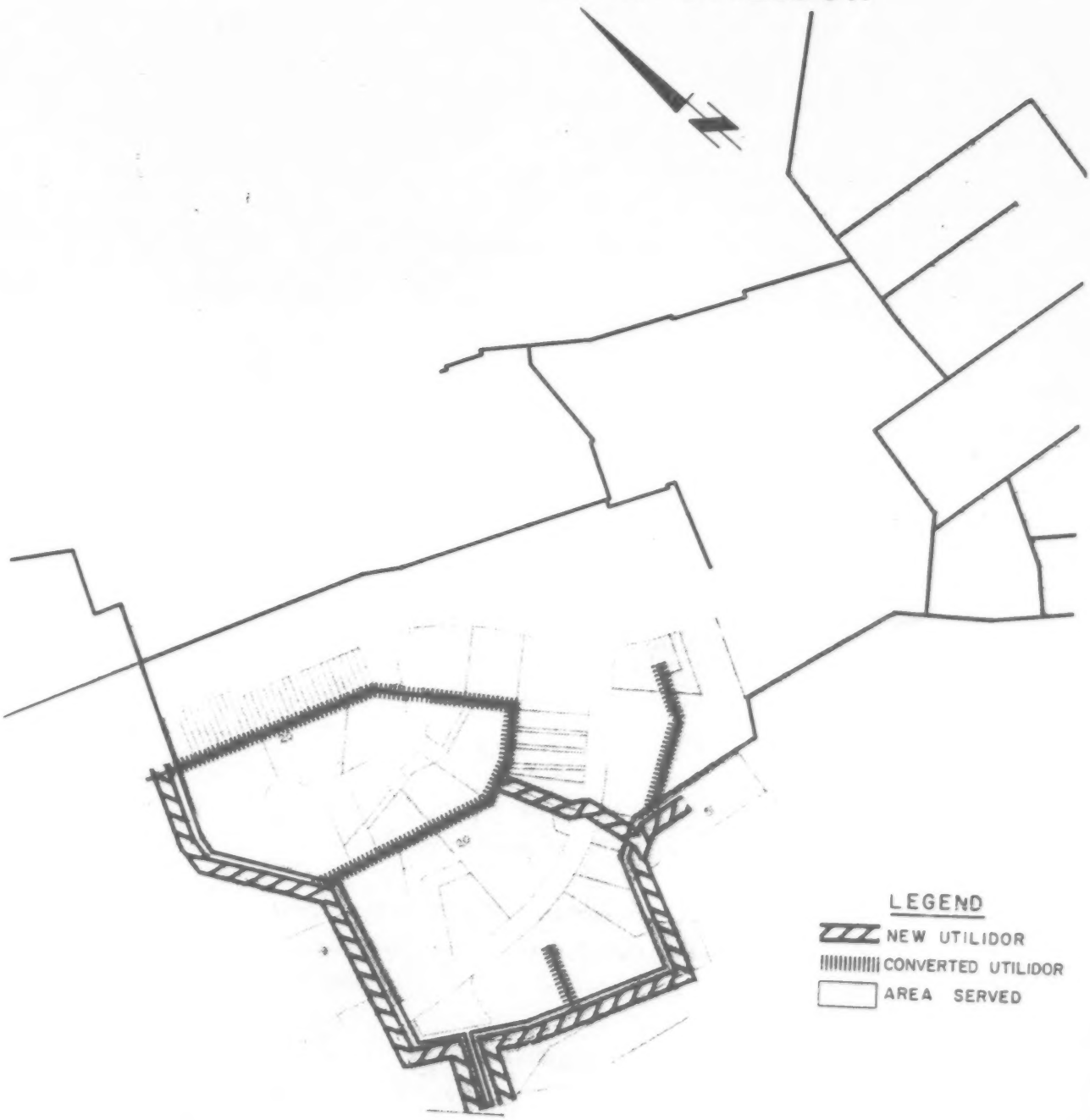
Exact matching is impossible. However, best fuel economy is achieved by supplementing LTW system heat requirements with HTW heat in winter, rather than discarding surplus waste heat in summer. This consideration argues in favour of transferring the largest number of customers needed to use all waste heat under summer conditions of peak availability. At the same time though, each additional customer transferred increases the capital expense of new heat exchangers, sized for LTW operation, and of building new utilidors or converting existing ones to LTW service. A point is reached where returns diminish rapidly.

Consequently, considerable care has been taken in identifying a group of consumers to transfer, to achieve a good balance between energy saving and capital cost. The capital costs and energy savings for several trial groups have been analyzed, considering the actual lengths of utilidor that would have to be built or converted, and considering the effects that both diurnal and seasonal variation in available heat and heating loads have on matching and actual heat recovery.

Through this process, a conceptual LTW system and customer group was developed.

The layout LTW system is shown in Figure 33. It would serve NCPC's fuel tanks, the water treatment plant, several warehouses, and a variety of commercial and residential buildings. The existing utilidor does not have room for additional pipes, so new utilidor, paralleling the existing one, would be needed where shown. Other runs of HTW utilidor would be converted to LTW. Figure 34 shows a cross section of new LTW utilidor. Pipe restraints and expansion joints would resemble those in the HTW system.

The consumer group would require 2870 MMBTU/mo in July and 11,730 in February, as compared to an availability of 4175 and 9930 MMBTU in the



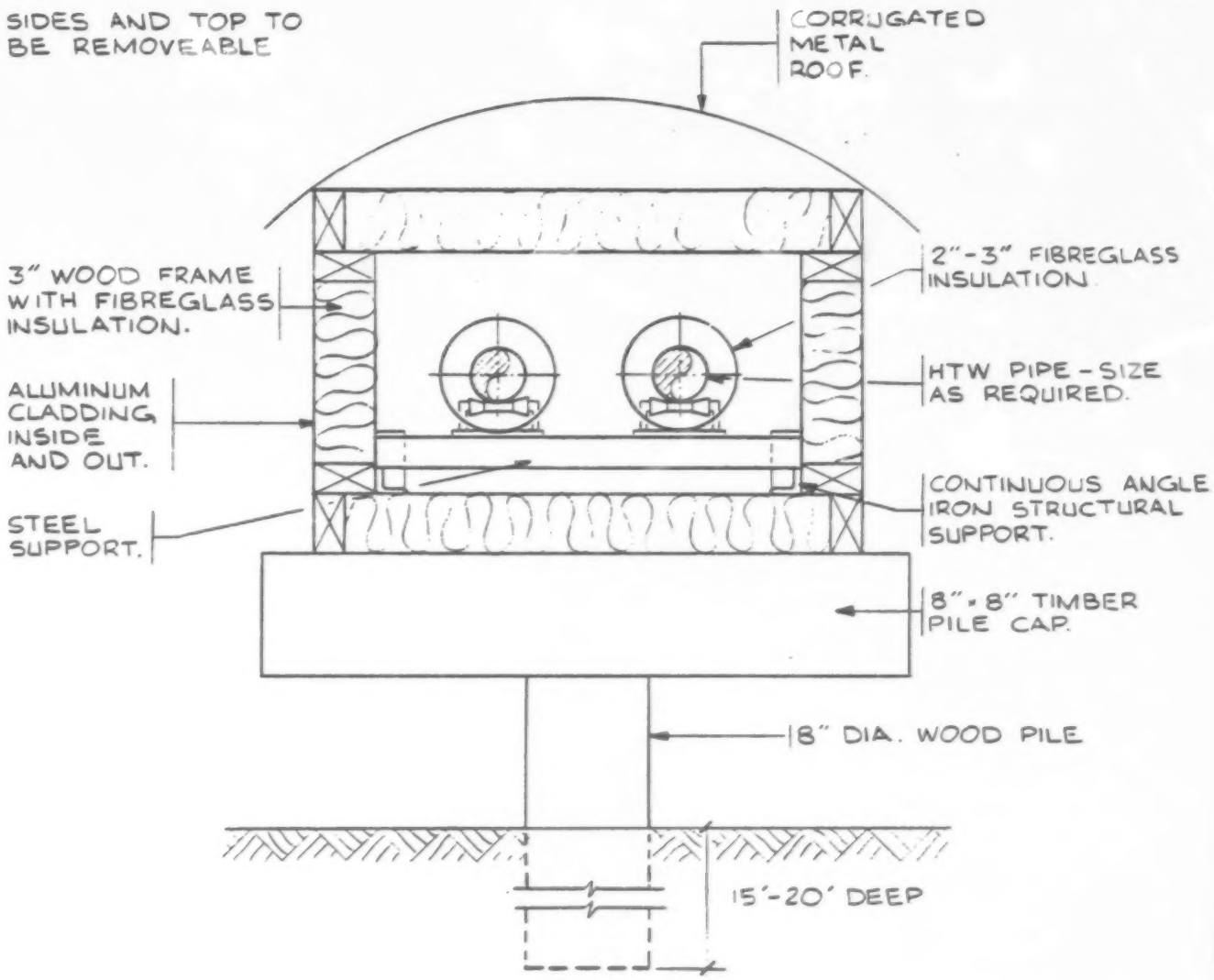
INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

SCALE : 1 : 5000

VOL. II FIGURE 33

TYPICAL SECTION LOW TEMPERATURE WATER UTILIDOR


SIDES AND TOP TO BE REMOVEABLE
CORRUGATED METAL ROOF.
2"-3" FIBREGLASS INSULATION.
3" WOOD FRAME WITH FIBREGLASS INSULATION.
HTW PIPE - SIZE AS REQUIRED.
ALUMINUM CLADDING INSIDE AND OUT.
CONTINUOUS ANGLE IRON STRUCTURAL SUPPORT.
STEEL SUPPORT.
8" x 8" TIMBER PILE CAP.
8" DIA. WOOD PILE
15'-20' DEEP

INUVIK, NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

N.T.S.

VOL. II FIGURE 34

same two months respectively. Consequently, 1300 MMBTU/mo would be discarded in July, and the HTW system would be called upon to provide 1800 MMBTU in February. Further reduction in the amount discarded in summer would entail construction of additional new utilidor, and capital costs would outweigh benefits.

The operation of the LTW utilidor was modelled using Hydrotherm III. Successive runs confirmed the necessary diameters of pipes, and this information was used in estimating capital costs of new utilidor and utilidor conversion. Runs also confirmed that the system would operate with a supply temperature of 230°F and return of 160°F. Supply pressure would be 300 ft of head (130 psi), and return 70 ft (30 psi).

Operational Characteristics of LTW System

As described, preliminary analyses of heat recovery and use were made in the course of selecting a consumer group and LTW system layout. With selection and layout planning both completed, system operation and efficiency was analyzed in more detail. The procedure is described below.

1. Temperature profiles were used to determine LTW system heat demand, both consumers and losses, by month.

2. Water treatment plant demands were added.

3. Electrical load profiles and data on the efficiency of heat recovery equipment were used to calculate the amount of waste heat recoverable, by month.

4. The difference between LTW requirements and heat available in each month was determined. Each difference represents either

supplementary heat required from the HTW system, or recoverable heat that must be discarded through powerhouse radiator systems.

5. A new load profile for the HTW system was determined by deleting consumers transferred to LTW, and rerunning the system at temperatures representative of the full annual range.

6. Fuel used by HTW boilers in each month was then recalibrated. The procedure used was as described earlier in the report, except that the new loads due to supplementary heating of the LTW system were added in.

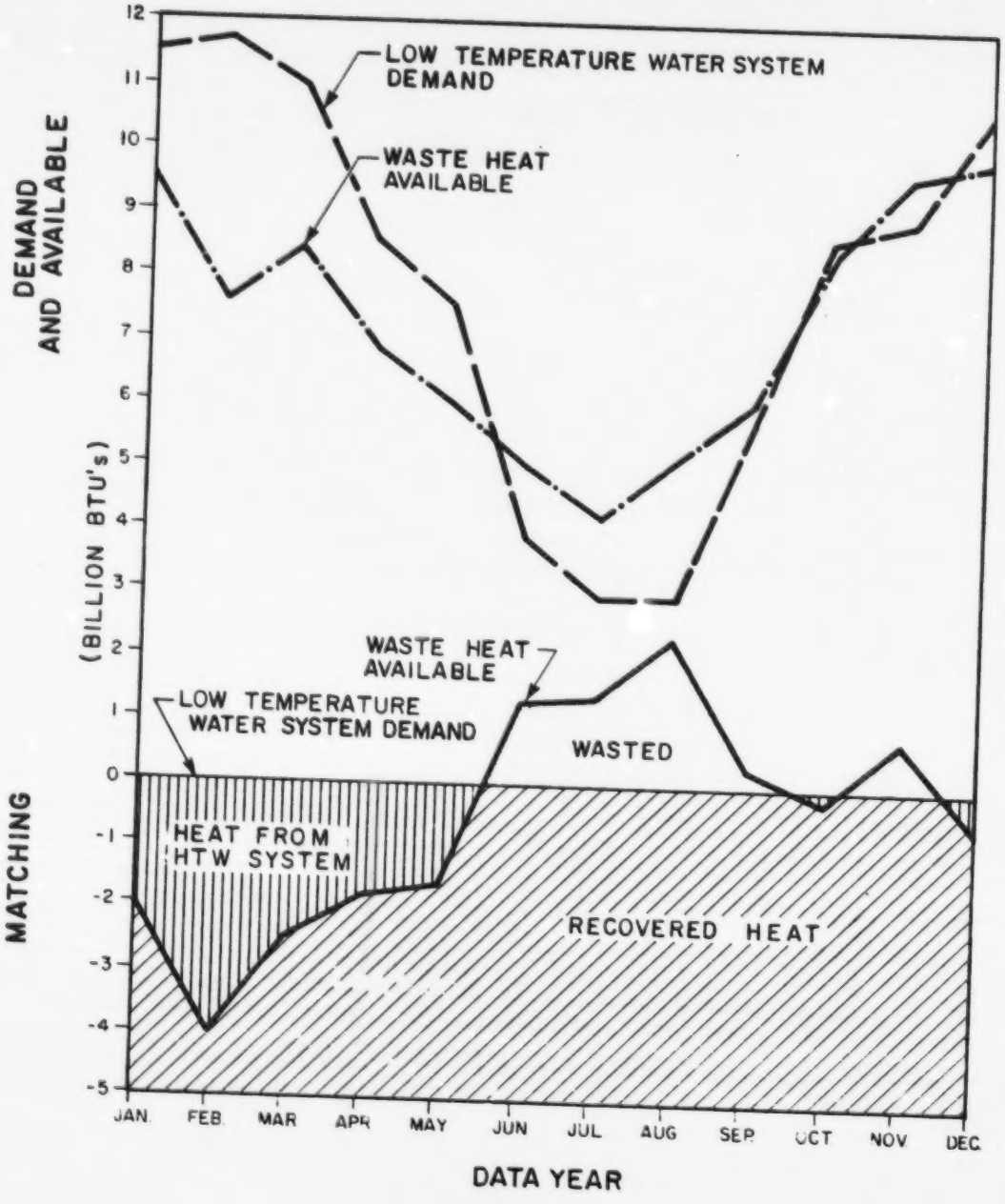
7. The difference between boiler fuel use by the HTW system with and without heat recovery was determined, and considered to be the measure of cost saving due to heat recovery.

The matching between recoverable heat and that used by the LTW system is shown in Figure 35, and the amount of HTW system fuel saving achieved is shown in Figure 36. Figure 37 shows energy flows in district heating facilities, before and after addition of the LTW system.

Cost Analysis

The capital cost of heat recovery equipment, new cooling equipment, plant piping and controls, distribution network additions and changes is estimated to be $4.8 million. The estimate is summarized in Table 25.

HEAT BALANCE
LOW TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM

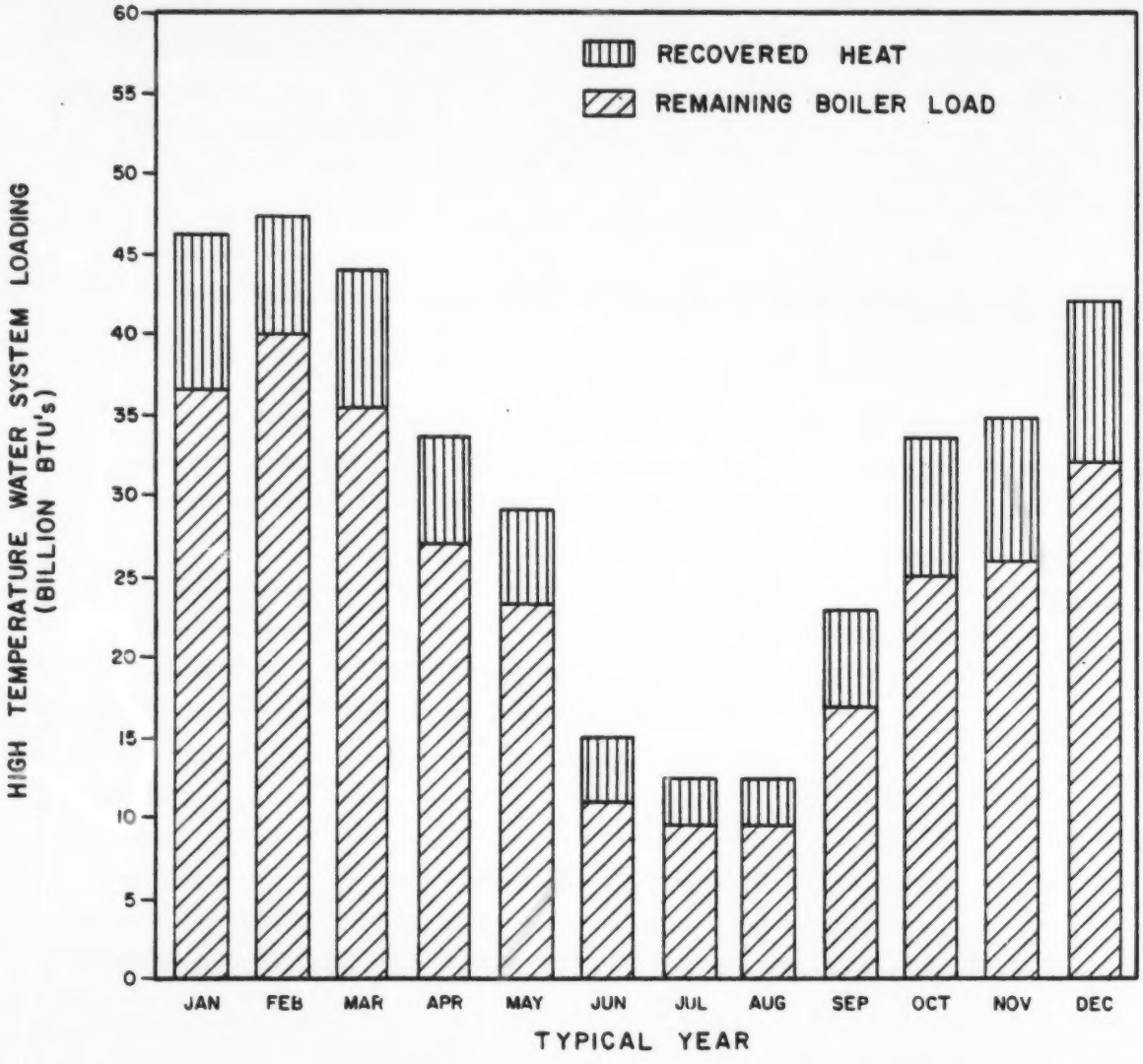


INUVIK , NWT

HIGH TEMPERATURE WATER
HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 35

BOILER HEATING LOADS WITH WASTE HEAT RECOVERY



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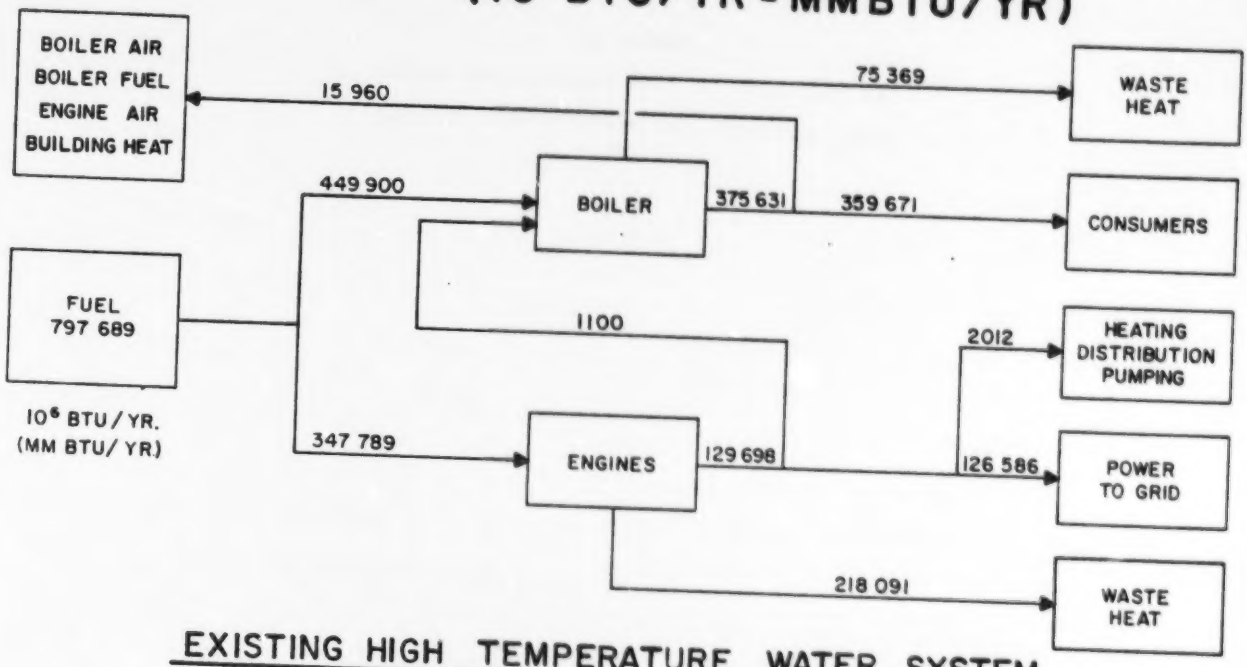
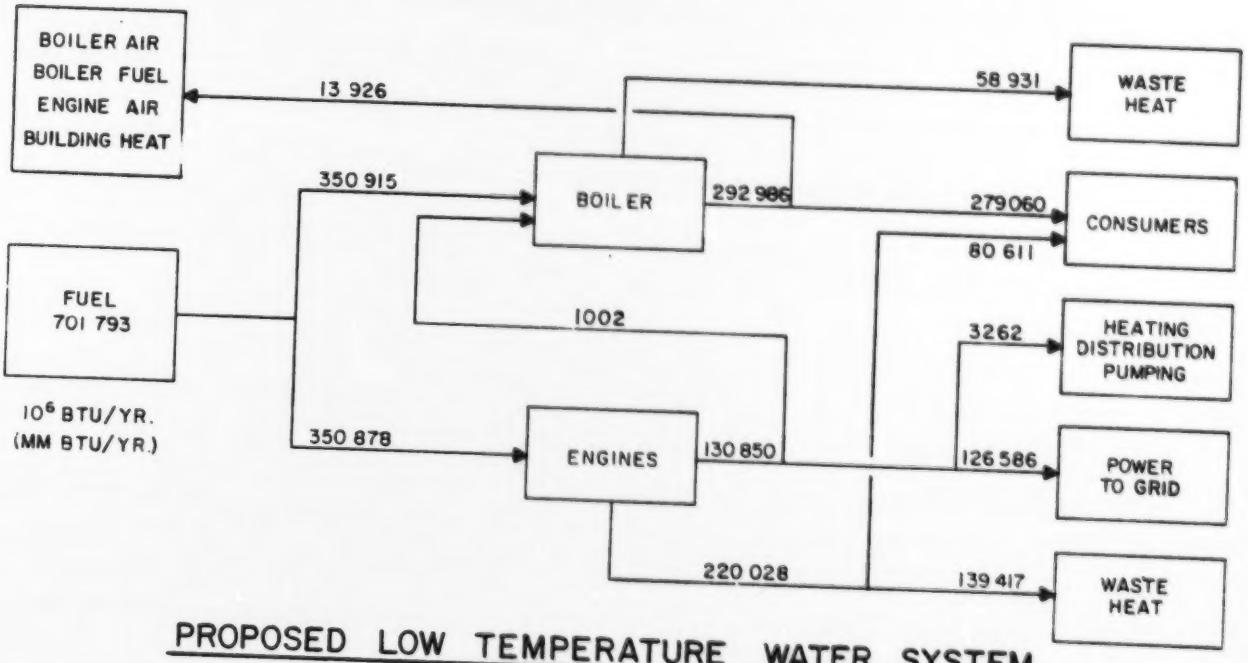
HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 36

ENERGY BALANCE COMPARISON
(10^6 BTU/YR = MM BTU/YR)



EXISTING HIGH TEMPERATURE WATER SYSTEM



PROPOSED LOW TEMPERATURE WATER SYSTEM

INUVIK , NWT

HIGH TEMPERATURE WATER HEAT DISTRIBUTION SYSTEM

VOL. II FIGURE 37

TABLE 25

CAPITAL COST OF LOW TEMPERATURE WATER HEAT RECOVERY AND DISTRIBUTION SYSTEM

Item	Cost
Heat recovery equipment	$ 2,353,000
Standby cooling (mostly exists)	216,000
Powerhouse piping and controls	530,000
Distribution network	1,681,000
Total	$ 4,780,000

Notes:

(a) Costs have been developed using published data, increased as described with respect to Tables 23 and 24, and from experienced costs for construction of utilidor systems. Costs are inclusive of engineering and normal contingencies.

Operations costs with the two systems are summarized in Table 26.

TABLE 26

OPERATIONS COSTS WITH AND WITHOUT HEAT RECOVERY ($1000/yr)

Existing HTW System	HTW	LTW	Total
Fuel	$ 3,670	0	3,670
Power	221	0	221
Overhead	1,506	0	1,506
Total	5,397		5,397

HTW & LTW Systems

Fuel	$ 2,862	0	2,862
Power	187	119	306
Overhead	1,506	100	1,606
Total	4,555	219	4,774

Annual Saving ($/yr)	$ 623,000
Present Value ($, 20 yr at 8%)	$6,117,000

The present value of the saving exceeds the present value of capital cost, and it appears that heat recovery could be made cost effective. The estimates above indicate a simple payback period of 7.5 years. The payback period with future savings discounted, at 8 percent, would be 12.5 years.

Conclusions

Recovery of waste heat and distribution of recovered heat through a low temperature water distribution system, similar in form and operation to the HTW system, seems to be cost effective. However, the payback period is long. Economic conclusions are quite sensitive to future variation in relative levels of capital and operations costs, fuel costs and discount rate, as well as to uncertainties in cost estimates.

COMPARISON OF ALTERNATIVES

Discussion

Alternatives for the recovery and distribution of waste heat that have been investigated include

- recovery of engine flue gas heat and transfer directly to the HTW system,

- recovery of about half of the available engine cooling heat and use by consumers of low temperature heat within NCPC's yard area,

- recovery of most or all of available engine cooling heat and transfer to the HTW system through a heat pump, and

- recovery of a large percentage of heat available from engine cooling and engine stacks, and distribution through a low temeprature heat distribution system.

Heat pumping is not cost effective. The principal characteristics of other systems are summarized in Table 25.

TABLE 27

COMPARISON OF HEAT RECOVERY ALTERNATIVES

Option	Heat Recovery		Capital Cost	Payback 8%
	Stack MMBTU/yr	Cooling MMBTU/yr	$	Yrs.
Stack heat to HTW	32,000	0	2,850,000	12.7
Cooling heat to NCPC yard	0	24,300	970,000	7.2
LTW utilidor	combined	80,600	4,780,000	12.5

Notes:

(a) Engine stack losses amount to 121,000 MMBTU/year, of which 43,500 MMBTU/yr (36 percent) might be recoverable.

(b) Engine jacket and valve cage cooling losses now amount to 52,000 MMBTU/year. All might be recoverable.

Conclusions

Of the options investigated, only the second one, use of low temperature heat for heating of fuel tanks and the municipal water supply, appears to have promise. The others are much less likely to be cost effective, owing to slow payback of relatively large capital costs.

It is recommended that NCPC give further consideration to the feasibility and cost of the second option.

REFERENCES

Associated Engineering Services Ltd., Inuvik High Temperature Water Distribution System Analysis, report to Northern Canada Power Commission, 1978.

R.N. Dalby & Associates Ltd., A Preliminary Assessment of the Comparative Economics of Potential Energy Supplies for Inuvik, Northwest Territories, report to Department of Local Government, Government of the Northwest Territories and to the Town of Inuvik, 1978.

Gulf Canada Resources Inc., Calgary (J.K.S. Loh, P.Eng., Manager, Frontier Development), letter report to the Energy, Mines and Resources Secretariat, Government of the Northwest Territories (Mr. Peter Hart), commenting on Stone & Webster Canada Ltd. (1984a and 1984b), August 27, 1984.

Stone & Webster Canada Ltd., Economic and Technical Feasibility of Distributing Natural Gas and/or Liquid Fuels to NWT Communities, report to the Government of Canada and to the Energy, Mines and Resources Secretariat, Government of the Northwest Territories, 1984(a).

Stone & Webster Canada Ltd., Followup Assessment of Parsons Lake and Cameron Hills Natural Gas Feasibility, report to the Government of Canada and to the Energy Mines and Resources Secretariat, Government of the Northwest Territories, 1984(b).